Safety, Efficacy and Functional outcome of flexible nailing (ESIN) in unstable fractures of both bones of forearm in children

A dissertation submitted to the Tamil Nadu Dr M G R Medical University in partial fulfillment of the requirement for the award of MS Branch II (Orthopaedic Surgery) degree March 2009 – 2011

CERTIFICATE

This is to certify that this dissertation '**Safety, Efficacy and Functional outcome of flexible nailing (ESIN) in unstable fractures of both bones of forearm in children**' is a bonafide work done by Dr Deeptiman James, in the department of Orthopaedic surgery, Christian Medical College, Vellore, in partial fulfillment of the rules and regulations of the Tamil Nadu Dr M G R Medical University for the award of M S Degree (Branch II) Orthopaedic Surgery under the supervision and guidance of Prof. Vrisha Madhuri during the period of his post graduate study from March 2009 to February 2011.

This consolidated report presented herein is based on bonafide cases, studied by the candidate himself.

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INDEX

AIM OF STUDY

- To assess the clinical and radiological outcome of elastic stable intramedullary nailing (ESIN) for unstable fractures of both bones of forearm in children.

OBJECTIVES

- To determine the clinical spectrum of patients who underwent ESIN for both bones forearm fractures.
- To assess functional outcome based on clinical parameters, Daruwalla’s grading and PODCI questionnaire / score.
- To assess fracture union, time to union, fracture alignment and verify re-establishment of radial bow (based on radiographs).
- To evaluate incidence of complications due to the injury, surgery and implant.

INTRODUCTION

Forearm diaphyseal fracture is one of the three common upper limb fractures in the pediatric population (1, 2, 3). Unlike the adult forearm diaphyseal fractures which has undergone tectonic shift in its management concepts (4, 5, 6, 7), its pediatric corollary continues to be viewed more cautiously. Having said that, the interest of the Orthopaedic surgeon has been piqued by the subtle but pragmatic encroachment of the operative interventions in an area hitherto considered as a stronghold for conservative management (8, 9, 10, 11).

Inadequate comprehension and exaggerated recommendation of the remodeling capacity of the immature skeleton has led the Orthopaedic fraternity to the precipice of accepting the unacceptable (8, 11). Orthopaedic literature is so flooded with the concept of conservative management for pediatric forearm diaphyseal fractures, that the anecdotes of poor outcome and possible options to overcome them have taken a beating (8, 10). In the early 70's and 80's, Mercer Rang and C Creasman took up the crusade to highlight this fact (12, 13, 14, 15). Though the possibility of complications in pediatric forearm diaphyseal fractures is relatively rare, they are certainly not negligible (15, 16, 17, 18). They highlighted the very clear and present danger of transferring the mandate to avoid and correct deformity to an overwhelmed remodeling unit, by ignoring the subtle signs of impending problems (15).

While this dissertation pitches us head on into the debate between operative and non operative management of pediatric forearm diaphyseal fractures, let it be amply clarified that indications for operative management are very specific and selective, and conservative management continues to be the mainstay for a vast majority of these cases (8, 9, 10, 13, 15, 18).

Though the concept of instability in forearm diaphyseal fracture is not new, it has acquired better acceptance and understanding with our growing knowledge (6, 13, 18). Various options have been put forward to internally stabilize the ‘unstable’ fractures. They include Kirschner wires, Steinmann’s pins, Rush rods, rigid plate osteosynthesis and even SS wires (6, 19, 20, 21). Metaizeau, from Nancy, France, has popularized the concept of using two prebent intramedullary flexible Titanium nails to recreate the interosseous space and provide three point fixations, while simultaneously providing for biological fracture healing and more convenient hardware removal (22). Flexible Titanium nails are physis sparing because they are introduced through the metaphyseal flare avoiding the physis.

I make an attempt to define the indications for operative management, highlight the learning curve in optimization of surgical technique, quantify the desired outcomes and address the complications of internal fixation of unstable pediatric forearm diaphyseal fractures with intramedullary flexible nails by retrospectively studying 26 patients who underwent flexible nailing for both bones diaphyseal forearm fractures from January 2004 to June 2010. Indications included open fractures, grossly unstable fractures, especially in older children or adolescents and unacceptable reductions. This dissertation assesses the outcome parameters and complications associated with this procedure, with intentions to look at the safety and efficacy of elastic stable intramedullary nailing and establish evidence based outcome measures for operative management in pediatric forearm diaphyseal fractures.

HISTORICAL REVIEW

If we run down the memory lane since the beginning of the documentation era to the modern day Orthopaedics, we will find that the various methods used for management of forearm diaphyseal fractures justify the dynamic nature of this specialty. Even before Walter Blount's declaration that pediatric fractures are different from adults (8); the Orthopaedic society was being prodded by the unpleasant results seen in adult forearm fractures (4). Robert Knight and George Purvis from Campbell Clinics in Memphis reported unbelievable 71% unsatisfactory results in adult forearm fractures treated with closed manipulation (4). They appropriated the blame on limited rotation secondary to angulation and loss of interosseous space. James Patrick promptly pointed out issues like forearm muscle atrophy and re-angulation of closed reduced forearm bones while due to cast loosening (23).

Open reduction was recommended when closed reduction failed. In the earlier years, forearm fractures were not routinely stabilized after open reduction and even the occasional case that was stabilized, an inadequate figure of 8 wires and catgut suture were used for the purpose (4). Not surprisingly, 85% patients were dissatisfied with the results. Kellogg Speed's effort to revolutionize adult diaphyseal forearm fracture management with cortical bone plates and primary on lay bone grafts proved futile. They only succeeded in introducing newer complications of graft fracture and cross union (4).

Not that the early results of internal fixation was anything spectacular. Sage (6) reviewed 555 adult patients with forearm diaphyseal fractures and categorized 69% of his patients with 'minimal' limitations with pronation and supination restricted up to 45 degrees!

High rates of non union and deep infection were reported in the early studies of open reduction and internal fixation of adult forearm diaphyseal fractures (4).

These results prompted Augusto Sarmiento to declare that early functional bracing for forearm diaphyseal fractures provided sufficient stability for the fracture to heal (5). He took pride and justifiably so, in reporting only one non union among 44 patients and restriction of only 20 degrees of terminal range of rotation.

While the operative management of adult forearm fractures still undergoes further refinement, the concepts in pediatric forearm fracture management have remained dormant. The astounding ability of immature growing skeleton to spontaneously correct deformities and minimal joint stiffness has made for significant leeway for conservatively managing these fractures (16, 24). However there is no proof that any rotational malalignment in a child will correct by maturity in forearm injuries. There is no justification for accepting gross angulation or inadequate stabilization of unstable fractures in anticipation that these will correct spontaneously and magically, especially when the limits for these children has been defined (3). Walter Blount was a firm believer that with a reasonably good alignment near normal results can be achieved with conservative management of most forearm fractures (8). Hughston also stressed that in children alignment is the most important goal of reduction (9). Both readily accepted minimal apposition and even ‘bayonet’ apposition. Evans (1951), Hughston (1962), Bohler and Blount (1967) were very critical of open reduction and internal fixation for pediatric forearm fractures (8, 9, 10).

Destot proposed the ‘Decolage’ theory of intrinsic rotatory displacement in forearm fractures in 1913 (8, 34). But Blount opined that though rotational deformities in children persist longer, eventually they disappear (8). He conceded that even a small amount of residual angulation can result in prolonged healing and limitation of pronation and supination, especially so in the mid-shaft forearm fractures. Aitken, Evans and Hughston swore by the remodeling capacity of immature forearm bones to correct any angular deformity (9, 10). Gandhi and Wilson (17) refuted their claim. They reviewed 1767 consecutive forearm fractures in children less than 12 years old. They found enough evidence to suggest that while an angular deformity of distal third forearm fracture can adequately remodel, the same could not be said for mid diaphyseal fractures in children. Moreover the capacity to correct angular deformity reduces drastically after 10 years of age (12, 30). With the distal radial physis fusing as early as 15 to 17 years (17, 24), there is hardly enough time left for spontaneous correction of deformities which takes 4 – 5 years on an average (17). This argument definitely solves the mystery of post traumatic forearm deformity in the remains of a 15 year old from the Paleolithic period (1). Fleischer reported using multiple wires for marrow wiring for displaced pediatric fractures in children in 1975 (2). Ligier and Amit also reported intramedullary fixation in children’s forearm fracture (57). Intramedullary fixation was offered as betterment over plate osteosynthesis in children. Jean Prevot and Paul Metaizeau (22) used flexible Titanium nails as a stabilizing intramedullary device. Hence, even though non operative treatment remains the mainstay of treating pediatric forearm diaphyseal fractures, several authors have attempted to point out the pitfalls and complications of this mode of treatment and have sought to identify the rare minority but clinically challenging group of patients for whom operative management should be reserved.

LITERATURE REVIEW

Applied anatomy (1, 2, 24, 58):

Several anatomic differences distinguish pediatric forearms from those of adults. The pediatric radial and ulnar shafts are proportionately smaller, with narrow medullary canals, and the metaphysis contains more trabecular bone. In addition, the periosteum in children is much thicker than that in adults; this feature can both hinder as well as help in the management of pediatric fractures.

The ulna is a straight, triangular shaped bone but the radius is rectangular distally, triangular in the middle third and cylindrical in the proximal third. The radius has a gentle bow along its shaft, which facilitates it's rotation around the ulna during the pronation and supination movement of the forearm. The two bones are held together by the annular ligament at the proximal end, the triangular fibro cartilage complex in the distal end and the interosseous membrane in the middle. This interosseous membrane is attached to the medial border of the radius and the lateral border of the ulna and extends from below the radial tuberosity to just proximal to the distal radio-ulnar joint. The interosseous membrane is stretched to its full length when the forearm is in neutral and up to 30 degrees supination. As the forearm is pronates, the radius rotates around the ulna and the membrane is relaxed.

The radial tuberosity located just below its neck provides attachment for the Biceps tendon and is located exactly opposite to the radial styloid process. This fact can be used as an intra-operative guide to assess rotational alignment. The radius and ulna articulate distally and proximally and function as a two bone complex. Hence a displaced injury to one bone is associated with an injury to the other. Forearm flexor muscles are divided into three groups. The superficial group includes the Pronator teres, Flexor carpi radialis, Palmaris longus and Flexor carpi ulnaris. The intermediate group includes Flexor digitorum superficialis and the deep group includes Flexor digitorum profundus, Flexor policis longus and Pronator quadratus.

Pronator teres has a humeral and an ulnar origin. The medial nerve enters the forearm through the tow heads of Pronator teres. It is inserted to the lateral surface of the middle third of the radius and is the primary pronator of the forearm. The superficial wrist flexors take origin from the common flexor origin over the medial humeral epicondyle and span the forearm to get inserted at or beyond the flexor retinaculum. The deep wrist flexors take origin from the volar surface of radius and ulna, span the wrist and get inserted into the phalanges and thumb. The Pronator quadratus is a small flat muscle which stretches across the distal forearm. It arises from the medial border of distal fourth of ulna and is attached to the lateral border of distal fourth of radius.

The dorsal forearm muscles are divided in to two groups. The superficial group includes the Brachioradialis, Extensor carpi radialis longus, Extensor carpi radialis brevis, Extensor digitorum communis, Extensor digiti qunti proprius, Extensor carpi ulnaris and Anconeus. The deep group includes the Supinator, Abductor pollicis longus, Extensor pollicis longus, Extensor pollicis brevis and Extensor indices proprius. Among these muscles the Brachioradialis and the Supinator are inserted to the forearm bones and play a significant role in fracture displacement. While the brachioradialis takes origin from the lateral supracondylar ridge of humerus and inserts in the radial styloid process, the

Supinator arises from the lateral humeral epicondyle, the radial collateral ligament, the annular ligament and the ulnar ridge, surrounds the proximal radius and is inserted in to lateral edge of the bicipital tuberosity and the dorso-lateral surface of the radial shaft midway between the oblique line and the head of the radius. The posterior interosseous nerve, deep branch of the radial nerve traverses this muscle.

Pronator teres and Pronator quadratus cause forearm pronation and the Supinator and the Biceps cause supination. It is primarily cause of these four muscles that the forearm fractures have an unpredictable rotational malalignment. In distal-third fractures, the proximal fragment will be in neutral to slight supination, and the weight of the hand combined with the pronator quadratus tends to pronate the distal fragment. It also tends to extend and displace laterally under the influence of the wrist extensors and Brachioradialis. Pronator quadratus tends to pronate radial shaft in all fractures proximal to its insertion. In proximal-third fractures, the distal fragment is pronated, and the proximal fragment is supinated. Biceps pull results in a flexed proximal fragment. Mid-shaft fractures tend to leave both fragments in a neutral position with the distal fragment slightly pronated and the proximal fragment slightly supinated.

While both proximal and distal physis provide growth potential to the forearm long bones, the distal radial and ulnar physis contribute 75% and 81% of the longitudinal growth of the long bones, respectively. Typical closure of physis is about 17 years in girls and 18 years in boys. The distal ulna physis closes about a year earlier than the distal radial physis. The proximal ulnar ossification center appears around age 10.

The literature review for this dissertation is discussed under two broad categories. The first category deals with remodeling of immature skeleton and the changing ideas regarding spontaneous correction of angular and rotational deformities and the second category takes us through the evolution of operative management for pediatric forearm fractures.

Remodeling of immature skeleton:

The often reiterated statement that pediatric bones are different from adult bones has its origin ingrained in the fact that pediatric bones are growing bones (8, 16, 26). This growth provides the potential for spontaneous correction of deformities (15, 27). This growth potential is derived from the epiphyseal growth plates (2, 26). Blount and Hughston, strong proponents of conservative management believed that 'mother nature' looks after the malalignment. Even rotational malalignment was believed to disappear with time (8, 9). Davis and Green reported very high incidence of re-angulation after closed reduction of complete diaphyseal fractures which underwent successful remodeling (16). The other extreme includes authors Luhmann, Schonnecker et al and Lascombes et al who have questioned the very concept of true bony remodeling (36). Rang and Ongden have proposed calling the post union bony changes as 'rounding off' as opposed to 'remodeling' (14). They postulated that the angular malalignment rounds off, thus decreasing the magnitude of the deformity and decreases the magnitude of interosseous compromise. But 'rounding off' has no effect on rotational alignment. Ulnar alignment influences cosmetic appearance of the forearm and radial alignment determines forearm rotation (29).

The remodeling capacity of children is further sub classified based on age, level of fracture and magnitude of angulation (28, 29, 30). Reynolds suggested that post injury growth rate diminishes after 2 years, which has generated interest in studies comparing the remodeling capacity before and after 2 years following an injury (30). Hughston stated that in a child younger than 10 years of age with a fracture close to the metaphyseal plate, 30 to 40 degrees of angulation will remodel (9). It is a fact that children younger than 10 years with a greater growth potential tend to achieve angular correction better than their older counterparts (29, 30). There have been reports of correction of gross malunion in infants and children less than 8 years (12). But spontaneous correction of angular malunion in older children (12 – 14 years) is highly unpredictable (12, 29, 31). Those in the age group of 10 to 12 years fall into a sort of grey zone, where clinical acumen is sought to define treatment guidelines. Fuller reported that spontaneous correction of deformities cannot be anticipated in children aged 11 years or more (12). Vitas et al concluded that there exist a significant correlation between fracture correction and change in epiphyseal plate angulation, in children younger than 11 years (30). Though the highest degree of correction achieved by them (13 degrees) was less than that proposed in other reports. It thus concluded that the epiphyseal plate exerts major influence over fracture remodeling. As growth plate activity diminishes beyond 10 years of age, the ability to remodel decreases after 10 years (30).

Distal radial fractures have better remodeling potential than mid diaphyseal fractures (2). Probably increased bone turnover in the metaphyseal region is reflected in the correction of distal radial fractures (30). But proximal diaphyseal fractures do not show similar tendency. Poor results following inadequate spontaneous correction of angulation of mid diaphyseal forearm fractures prompted Gandhi et al to recommend greatest caution while accepting any angulation at this level (15, 17).

The magnitude of angulation that can undergo remodeling varies with age and level of fracture (28, 29, 30, 37). Angulations in the plane of movement of the limb have better remodeling capacity. Variable acceptable ranges of radio – ulnar angulation and dorso – volar angulation have been proposed. Hughston accepted 30 to 40 degrees of angulation (9). Price published limits of angulation and malrotation in displaced fractures to be 15 and 45 degrees in children under 9 years and 10 and 30 degrees in children over 9 years, with complete displacement (3). Flynn et al proposed 15 to 20 degrees as the acceptable limit in children less than 8 years and 10 degrees in older children (29). Evans and Rang state that angulation is always accompanied by rotational malalignment (11, 14). Evans demonstrated correction of greenstick fracture deformity by rotating the forearm under image intensifier. The apparent angulation disappeared in the proper plane of rotation. We know that a volar angulated greenstick fracture is associated with a supination injury and a dorsal angulated greenstick fracture is associated with hyper pronation injury (24, 58). But no such indicator can be applied to complete both bones diaphyseal fractures of the forearm. In complete fractures various permutations and combinations secondary to the Supinator, Pronator teres and Pronator quadratus pulls ensures an unpredictable rotational malalignment (2, 24). Contrary to the old belief that rotational malalignment corrects with time, it has been proved time and again that they persist (10, 14, 17, 36). Malrotation of the forearm limits movement and is often reflected in the career options and employment chosen by the child in future life (34, 35, 38). To give due credit to a child’s adaptive prowess, limited pronation is compensated by shoulder abduction and internal rotation (36). Shoulder's ability to adduct and externally rotate in order to compensate for supination deficits is considerable lower. Malrotation of the forearm limits the movement of the forearm by the same degree as the rotational deformity of the bones.

Hence it is justified that a parent's concern and an Orthopaedic surgeon's aim should be to provide appropriate alignment in pediatric forearm diaphyseal fractures, especially so in complete mid diaphyseal fractures.

Operative management for pediatric forearm diaphyseal fractures:

An underlying defensive note is probably all that is common in several published reports about the operative management of pediatric forearm fractures (18, 19, 28, 29). Of course, there is no denying the fact that non operative management is the gold standard for most forearm fractures of the immature skeleton (8, 9, 16). But Ortega, Wrysch et al, Schmittenbecher, Vainionpaa et al and Nielssen and Simonsen have proposed very definite indications for internal fixation of these fractures (19, 28, 39, 40, 41). Reports regarding children requiring corrective osteotomy for malunited forearm fractures further strengthen the argument of 'a stitch in time saves 9' (15, 38, 39, 42). The complication rates sited in the case series reporting operative management of pediatric forearm fractures is not only less than those cited in the adult group, but far outweighs the complications and risk associated with any forearm osteotomy(18, 38, 42, 44). Majority of the pediatric fracture bone remodeling occurs during the first 2 years of the post trauma period. After this period the remodeling potential undergoes steady decline. Hence if a child has less than or equal to 2 years of growth left then it is definitely a risk to expect the fracture union to remodel (30). Therefore, unstable and malaligned both bones forearm fractures in older children and adolescents are prone for malunion, thus compromising the function and cosmetic appearance of the limb. Open osteoclasis and drill osteotomy have been described for correction of pediatric forearm malunion. Though a rare phenomenon, malunion is an unfortunate complication witnessed in displaced, unstable fractures which are inadequately reduced. Pediatric fractures gel together quickly and makes closed manipulation difficult. This is a strong argument in favor of primary internal fixation in unstable both bones forearm fracture in older children. In order to avoid irrational and insensible use of operative management in pediatric forearm fractures, the following indications are laid down:

a) Instability
b) Unacceptable alignment
c) Open fractures
d) Fractures associated with vascular injury
e) Refracture with displacement
f) Older children / adolescents

Unstable fractures are defined as complete diaphyseal fracture of both bones of the forearm, at or near the same level with convergent displacement (37). The interosseous space is compromised and rotational malalignment is unpredictable. When angulations after attempted reductions are beyond the acceptable range or re angulation occurs after successful closed reduction, then internal fixation after open / closed reduction is indicated (19, 39, 53). Open fractures are considered inherently unstable (28, 39). An adequate debridement should always be accompanied by internal fixation (28, 36).

Grossly displaced diaphyseal fractures in children older than 10 years should be fixed internally. In these patients closed reduction may prove difficult as the Pronator quadratus or interosseous membrane may interpose between the fractures fragments (18, 36, 37, 39, 45).

Open reduction and internal fixation in pediatric population came to limelight following Willis Campbell publications in his highly regarded textbook ‘Operative Orthopaedics’ in 1939 (1). He approved operations in children’s forearm fractures by illustrating open reduction and internal fixation of a distal third forearm shaft fracture in a patient who was perhaps as young as 11 or 12 years, when he failed to achieve satisfactory alignment after conservative methods. Daruwalla, Fuller, Schmittenbecher, Creasman and Neilsen have furthered the cause of operative management when appropriate indications are cited (46, 12, 15, 30).

Various options are available for internal fixation. Let us broadly classify them into plate osteosynthesis and intramedullary devices. Failure of low profile 1/3rd tubular plates with resultant nonunion has been described (28). Far better results have been reported with the use of AO compression plates for open reduction and internal fixation (19, 20, 28). Small diameter of the distal third of Ulna may occasionally prevent use of these plates. Successful single bone plating with closed manipulation of its counterpart, in both bones fractures has been carried out. Though plate osteosynthesis provides good anatomical reduction and stable, rigid internal fixation, problems have arisen with extensive periosteal stripping resulting in delayed union in few cases (28, 31). Implant removal has its associated complications and risks (29, 31).

Refracture following repeat trauma to a healed fracture has been qualified as an indication for operative management. Pediatric forearm refracture with retained plates as well as those occurring after removal of plates or any intramedullary device requires internal stabilization with flexible intramedullary nails.

The use of intramedullary devices can be traced back to the reports of Knight and Purvis in the late 1940s, when SS wires and Kirschner wires were used for internal fixation in adults (4). Inadequate stability led to poor results. Rush brothers proposed the modified Charnley's three point principle for cast immobilization and promoted the idea of using a straight rod in a curved bone to achieve stability (6). Kuntsher in 1940 popularized the concept of increasing the contact area between bone and intramedullary device to achieve rigid fixation (6). Adaptation of Kuntscher nail for forearm fractures failed to elicit desirable results (6). Sage developed a modified triangular nail, with rounded circumference proximally (6).

Passing an intramedullary device in to Ulna is a straight forward business by conforming to the anatomy of the bone. It's not easy to do the same in the Radius because of the inherent radial bow. Hence some authors advocated passing the intramedullary device halfway to stabilize a proximal fracture. Another school advised passing a prebent device aimed obliquely against the cortices. Multiple intramedullary pinning was described in patients with wide canal and inherently unstable fracture pattern. Intramedullary fixation of children's forearm dates back at least to Fleischer's 1975 report in the German literature in which he called it 'marrow wiring'(1). Displaced oblique and comminuted mid shaft forearm fractures in children above 5 years are considered indications for intramedullary fixation. Closed intramedullary nailing (also known as indirect reduction and internal fixation) of diaphyseal forearm fractures in adolescents was later reported in English literature by Ligier et al, Amit et al and others (57). Intramedullary fixation has several advantages over plate osteosynthesis including improved cosmesis because of smaller incision and less deep tissue dissection. Though the rotational stability of pediatric forearms treated with intramedullary fixation is considered doubtful. Blasier and Salaman suggested that the strong periosteum in children prevents rotation. Ono et al have found that intramedullary fixation of both bones reduced fracture rotation to one eighth of that in unfixed fracture (57).

Jean Prevot and Paul Metaizeau developed elastic stable intramedullary nailing (ESIN) of pediatric forearm bone fractures in the late 1970s at the Children's Hospital, Nancy; France. Metaizeau published his landmark article in 1986 where he reported 85 cases of pediatric forearm diaphyseal fractures which were internally fixed with prebent flexible Titanium nails (22). He recreated the interosseous membrane and stabilized the fractures fragments with the springiness and dynamic three point fixation principle of the nails. This heralded the arrival of an effective, minimally invasive technique of internal fixation particularly suited to the pediatric population. Several authors have published positive outcome with the use of flexible nailing in children's forearm (37, 40, 41, 44, 45, 47, 48). The ability of the flexible nail to stabilize the entire length of the fractured bone while leaving the fracture biology undisturbed and recreating normal anatomical bowing of the forearm bones is unparalleled (31, 37). Implant removal is also less tiresome and associated with no complications with regards to plate osteosynthesis (31). Incidence of complications with flexible nailing is significantly less as compared to other forms of internal fixation (31, 43, 49). Low complication rates probably reflect a gentle learning curve for this technique. Less complications with flexile nailing of course does not allow the surgeon to by pass the technique and principles of the Elastic stable intramedullary nailing (57).

Recent suggestions include using long prebent Kirschner wires instead of Titanium nails (18, 50, 51, 52, 54). The arguments of cost effectiveness and easy availability are certainly commendable, especially in a developing country like ours. But the differences in the metallurgy and biomechanical properties of stainless steel and Titanium must be taken into account. Contradicting reports comparing the biomechanical properties of stainless steel and Titanium nails have been published. Mahar et al reported higher resistance to torsion and axial stress with Titanium nails used for in vivo femoral fracture fixation (59). Wall, Jain and Vora found better clinical results with stainless steel intra medullary nails (60). Steel is more rigid with a higher elastic modulus compared to Titanium, hence expected to provide better fracture stability (54). But Titanium implants have less gap closure and decreased nail slippage in response to loading increments. Stress distribution is believed to be more even with Ti nails. Hence, Titanium nails provide better biomechanical stability (62). Titanium is more deformable, hence allows wider medullary contact area and increases fracture stability. Rigid Stainless steel implants cause stress shielding, osteolysis of surrounding bone and increase the risk of re fracture after implant removal (61, 63). Though K wires have greater antero-posterior and torsional stiffness and require greater force for failure, they also have higher cut out rate and fail at smaller displacement, whereas the flexible Titanium nails can recoil thus avoiding new fracture lines (63). Intact soft tissue of forearm has a significant role in ESIN principle. Patients with extensive soft tissue loss, neurological impairment and neuromuscular imbalance are considered inappropriate for internal fixation with intramedullary devices (45).

A common dilemma is whether or not to immobilize the forearm after surgery. Early authors as well as AO manual consider immobilization unnecessary (37, 57). The purpose of the intramedullary device is to regain the normal anatomical alignment of the forearm. Ulnar alignment accounts for the cosmetic appearance of the forearm and radial alignment provides forearm function (2). While the distal deformity undergoes rapid remodeling, mid diaphyseal and proximal diaphyseal fractures do not share the same destiny (17, 29, 30). This is because nearly 80 % of the forearm growth occurs at the distal radial and ulnar growth plates (2, 24, 26). Maintenance of radial bow, angular and rotational alignment and interosseous space is essential for normal supination and pronation movements of the forearm (11, 74). Since the mid diaphyseal fractures have low potential for remodeling, it is important to re establish the radial bow. The maximal point of radial bow varies with age, but is generally located at mid third – distal third junction region of the radius (58, 67). The maximal point of radial bow may migrate distally following intramedullary fixation.

We did not observe any limb length discrepancy. Lengthening after internal fixation is commonly described in femur fractures (29, 55). Sometimes the distal ulna physis may grow faster causing rapid ulna growth. Distal radio-ulna joint subluxation has also been described with nailing of radius alone in both bones fractures (44, 75). A residual deformity of more than 10 degrees in an older child is associated with restriction of forearm rotation (3).

A single case series of 15 both bone forearm fracture treated with elastic nail has been reported from India (55). But no standardized data regarding outcome analysis in unstable both bones forearm fracture is available in our country. We attempt to introduce the concept of flexible nailing to optimize the management of grossly unstable and displaced diaphyseal forearm fractures in indicated categories.

MATERIALS AND METHOD

A retrospective descriptive study was carried out in Pediatric Orthopedics department of Christian Medical College, Vellore from May 2009 to October 2010. The study was approved by the Institutional review board. 40 children underwent elastic stable intramedullary nailing of forearm bones from January 2004 to June 2010. Out of these 40 children, 26 had both bones diaphyseal forearm fractures and underwent ESIN for both radius and ulna. 10 patients underwent flexible nailing of the Ulna alone and 3 underwent flexible nailing for isolated radius fracture. One patient had ESIN for second refracture of both bones of the right forearm which was earlier managed conservatively. He declined participation in this study.

26 patients who underwent flexible nailing for both bones forearm diaphyseal fracture were included in this study. Their medical records were reviewed. Baseline and peri-operative data of these patients was collected (Table 1). These patients were followed up through office consultation and OPD. Pre and post operative follow up radiographs were analyzed. The elbow, forearm and wrist movement of the operated limb was clinically assessed and compared with the non operated limb. Forearm rotation in each patient was clinically graded according to the Daruwalla's system (46). PODCI upper limb questionnaire was administered to 21 children (64). All children were over 10 years old at the time of follow up and were administered the self reported adolescent PODCI Outcomes questionnaire.

Inclusion criteria:

All patients who underwent ESIN for

a) Complete/displaced/unstable diaphyseal fracture of both bones of forearm

b) Oblique, transverse and short spiral diaphyseal fractures

c) Open fractures / polytrauma

d) Refracture

Exclusion criteria:

a) Pathological fractures

b) Prophylactic nailing

c) Nonunion and delayed union

Among those who were excluded, 3 patients had closed flexible nailing of Ulna for Monteggia fracture dislocation. 6 patients who underwent nailing of Ulna alone had associated distal radius metaphyseal fracture which was stabilized with either Kirschner wire and/or cast immobilization. 1 patient had gap nonunion of the ulna following an open injury and bone loss. Flexible titanium nail was used for second stage stabilization with bridging bone graft in the gap non union.

Among the Radius nailing group, one child had a pathological fracture secondary to Aneurysmal bone cyst of the distal radial diaphysis. Another child had flexible nailing for internal fixation of Radial neck fracture. One child underwent corrective osteotomy, open reduction and internal fixation with flexible titanium nail for a malunited Galeazzi fracture with functional restriction.

Clinical outcome:

Clinical evaluation involved assessment of elbow range of movement, forearm supination and pronation, wrist dorsiflexion and palmarflexion range with Patrick's Goniometer and measurement of both upper limbs from the lateral epicondyle to the tip of radial styloid. Surgical scars were inspected. Wrist, thumb and finger extensors were evaluated to look for tendon insufficiency. Distal sensation and motor power was examined.

Patients were divided in to two groups. Group A included patients with more than 2 years follow up and group B included patients with less than 2 year follow up.

Radiological outcome:

Pre operative radiographs were verified to confirm the level and pattern of the diaphyseal fractures. All fractures were classified according to the AO (PCCF) pediatric fracture classification system. Post operative follow up radiographs were taken after 4 and 8 weeks respectively.

Radiological bony union was defined as bony trabeculae traversing the fracture and evidence of bridging callus along three cortices of the diaphyseal bones (65). Radial and ulnar diaphyseal angulation was measured using mid diaphyseal mechanical axes of the proximal and distal fragments. These angles were measured in the antero-posterior plane as well as in the medial – lateral plane (15, 65).

Rotational alignment could not be assessed due to lack of standardized radiographs. Evans described a 23 degree radial tuberosity view to assess rotational malalignment (15). In this view the X ray tube is angled 23 degrees off the perpendicular. It was difficult to visualize the radial tuberosity in children.

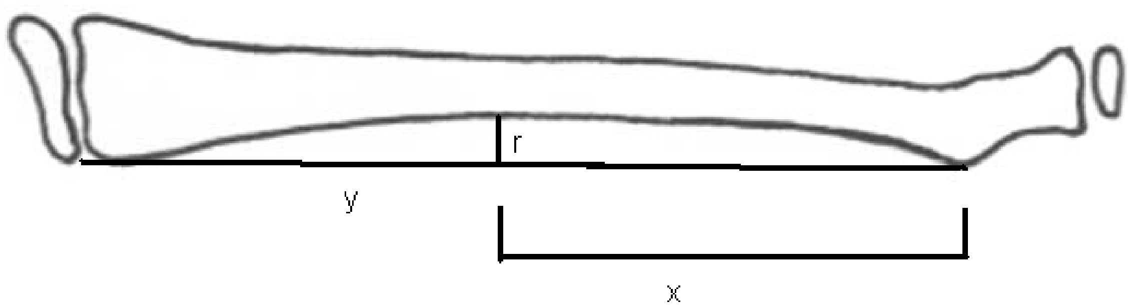
In a true tuberosity view of the forearm, the radial styloid process should point laterally whereas the bicipital tuberosity is most prominent and points exactly opposite to the medial aspect. Both the radial styloid process and bicipital tuberosity become inconspicuous on a true lateral radiograph. Any alteration in these arrangements implies a rotational malalignment of the radius.

Similarly, the ulnar styloid process and the coronoid process are visualized clearly in a lateral projection and are present at two opposing end. But in a tuberosity view, the ulnar styloid process and the coronoid process are foreshortened.

Creasman et al have also described taking a series of radiographs of the normal forearm taken in varying degrees of rotation and comparing them with the patients' radiographs (15). This method is fraught with inter-observer and subjective variation. Creasman described this method for research purpose and not for regular follow up of patients in OPD. Hence we did not use this method.

We used modified Schemitsch and Richards method for assessing radial bow in all post operative patients.

In 1992, Schemitsch and Richards described a method based on the measurement of three basic distances of the radius on the anteroposterior (AP) radiograph. Radial bowing was characterized by a maximum distance and site referred to as the total radial length (66). This measurement was made for skeletally mature patients. Firl et al published a modification of this method in 2004 (67). This modification was meant to assess the maximal radial bowing and locate its site with respect to the total radial length in immature skeleton.



Radial bowing is best measured on standardized projections taken in neutral rotation. On an AP radiograph of the forearm, the length of the radius (y), the location of maximum radial bow and the maximal distance of the radial tuberosity from this point (x) are measured. The distance (y) is measured from the bicipital tuberosity to the distal radio-ulnar joint. In children with incomplete ossification, the distal radial epiphysis was used as the reference point. At the point of maximum radial bow, a perpendicular line (r) is drawn on to (y) and the distance is measured. This value indicates the maximum radial bow. To determine the site of maximum radial bow, the distance from the bicipital tuberosity to the point of maximum bow is divided by the length of the entire bow and expressed as a percentage (x/y x 100). By applying this method, bones of different length can be compared. Due to the high variability of bone length in different patients, the maximum radial bow (r) is reported as a percentage of the radial length (y), calculated as r/y x 100.

The mean distance of the site of maximum radial bow is 60.39% (SD ± 3.74%; 95% CI 59.65 to 61.14) of the radial length (67). The mean value of maximum radial bow is 7.21% of the total radial length (SD ± 1.03%; 95% CI 7.00 to 7.41) (67). While the length of the radius and the maximum bowing increases with age, the site of maximum radial bowing (x/y x 100) remains constant. Site of maximum radial bow is at 60% of the radial length from the bicipital tuberosity and that the maximum bowing should be below 10% of the radial length.

Functional outcome:

Functional outcome was measured according to the Daruwalla's clinical grading and PODCI upper limb assessment scores (46, 64).

Daruwalla's Clinical grading:

EXCELLENT	Movements equal on both sides
GOOD	Limitations of up to 20 degrees of rotation on injured side
FAIR	Limitation of 20 to 40 degrees on the injured side
POOR	Limitation of 40 degrees or more rotation on the injured side

Jimmy Daruwalla proposed a grading system for forearm function in children in 1979 (46). He compared the range of supination and pronation of the operated and normal forearms. Those children with equal range of movements in both forearms were classified as excellent. Those who had loss of up to 20 degrees of supination / pronation as compared to the normal side were considered as good. Children whose range of forearm rotation was 20 to 40 degrees less than the normal side were graded as fair. Children with more than 40 degrees loss of forearm rotation compared to the normal side were graded as poor.

The AAOS has developed the Pediatric Outcome Data Collection Instrument (PODCI) (64). This instrument was designed to collect patient-based data for use in clinical practices to assess the effectiveness of treatment regimens and in musculoskeletal research settings to study the clinical outcomes of treatment. PODCI tool has been designed for 'routine medical visit' setting. This tool has been broken down into individual scales. The upper extremity scale measures the ability to perform activities of daily living and upper extremity function at school.; the trasfer scale is designed to measure routine motion and mobility; the sports scale is designed to measure higher functinal abilities making participation in sports possible; the pain scale is designed to evaluate pain that has occurred over the previous week; the happiness scale is designed to rate self satisfaction and the ability to fit in and be like other children and the global scale is an average of all the previously mentioned scales.

21 patients were administered the PODCI questionnaire during their follow up visit. Standardized and normative scores were calculated with the help of score sheets provided along with the instrument software. The PODCI instrument, developed by the AAOS in

collaboration with orthopaedic specialty societies, is freely available on its web site for use by individuals and organizations without copyright restrictions or registration. Its reliability and validity has been approved (64). Data entry sheets and score cards are avialable along with the questionnaires. There are three questionnaires. One is for the pediatric population (children for 2 to 10 years old). This questionnaire has to be filled by the parent of the child. Adolescent versions (for children older than 10 years) of the questionnaire comes as a self reported and a parent reported type. The Adolescent (self-report) Questionnaire is intended for children up to 18 years old who are capable of completing the form independently. This questionnaire is similar to the Adolescent (parent-report) Outcomes Questionnaire, but does not offer a response option indicating that the respondent is "too young for this activity." The Adolescent (parent-report) Outcomes Questionnaire is designed to be completed by the parent/guardian with knowledge of the 11 to 18 year old child's conditions. All out patients were older than 10 years were able to self report the questionaire. PODCI generates eight scales:

- Upper Extremity and Physical Function Scale: Measures difficulty encountered in performing daily personal care and student activities.
- Transfer and Basic Mobility Scale: Measures difficulty experienced in performing routine motion and motor activities in daily activities.
- Sports/Physical Functioning Scale: Measures difficulty or limitations encountered in participating in more active activities or sports.
- Pain/Comfort Scale: Measures the level of pain experienced during the past week.
- Treatment Expectations Scale: Measures the long term expectations of treatment.

- Happiness Scale: Measures overall satisfaction with personal looks and sense of similarity to friends and others of own age.
- Satisfaction with Symptoms Scale: Measures the patient's acceptance of current limitations should this be a life long state.
- Global Functioning Scale: A general combined scale calculated from the first four scales listed above.

Since we wanted to measure the functional outcome of children’s upper limbs, hence we considered the upper extremity scale as an effective tool for objectively assessing fucntional outcome in our patients. For this study we selectively choose the upper limb assessment score (Appendix 2) to assess the functinal outcome of the children undergoing flexible nailing of both bones for diaphyseal fractures of both bones of forearm. For a valid score at least 4 out of the 8 questions had to be answered. The questionnaire was administered without any changes. Help with translation was provided for some patients. Children were told to complete the questionnaire for the unaffected side first in order to accustum themselves with the tool. Then they filled the same questionnaire tool for the operated limb.

SURGICAL TECHNIQUE FOR ELASTIC STABLE INTRAMEDULLARY NAILING (AO MANUAL) (57)

Nailing approaches:

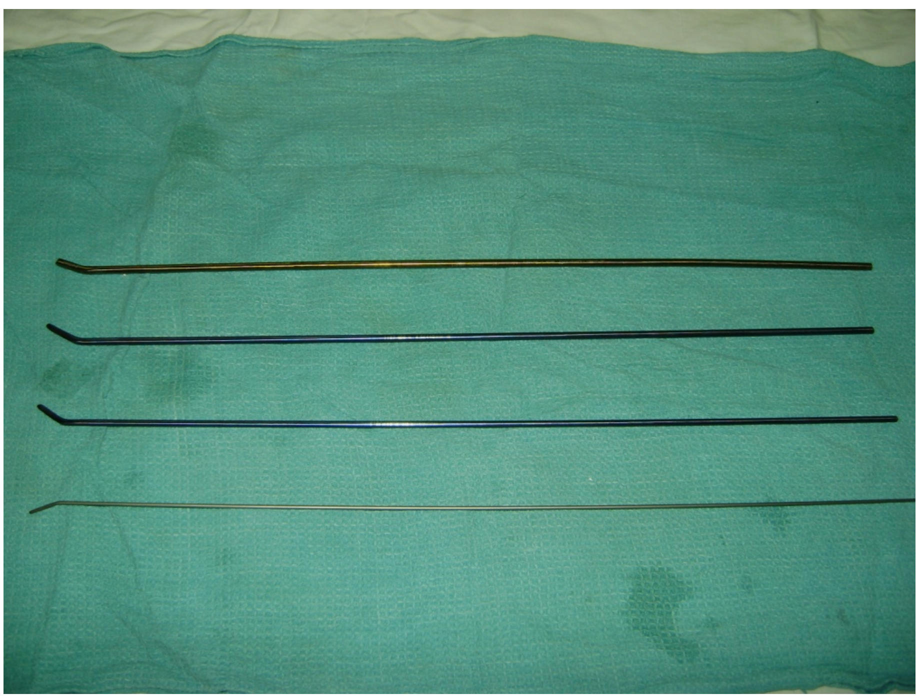
There are specific approaches available for nailing the radial and the ulnar shafts.

1. Radius: retrograde from the lateral or the dorsal (Lister's tubercle) entrance site is the only technique utilized. Ante grade nailing of the radius is contraindicated because of high chance of injuring the Posterior Interosseous nerve in the proximal forearm.

2. Ulna: can be nailed either through an ante grade or a retrograde approach. Ante grade from the lateral cortex of the olecranon and retrograde from the medial cortex of the distal metaphysis.

FRENCH AWL (Instrumentation for ESIN)

ESIN INSTRUMENTS



Interosseous spreading:

Interosseous membrane is spread in an oval fashion by placing the nail tips in opposition so that they are facing each other. Thus both bones are stabilized by recreating their physiological curve.

Surgical technique:

Surgical stabilization of radius and ulna requires separate standard insertion sites, one at each end of the forearm. The radial site is distal and the ulnar site is proximal. This procedure is guided and aided by intra operative image intensifier.

Distal dorsal radial insertion:

A 2 – 3 cm transverse or longitudinal incision is made over the palpable dorsal tubercle of the radius. Next the subcutaneous tissue is spread and the fascia is incised to expose the tubercle. After retracting the incision, the awl was placed directly on the tubercle adjacent to the third compartment containing the extensor tendon. Care is taken to avoid injury to the tendons. The awl is directed anteromedially as it is drilled to perforate the posterior cortex. Size of the awl should correspond to the size of nail being used. For example if a 3 mm nail is to be inserted, then a 3 mm awl should be used to make the entry point. Use of larger awl can result in nail loosening and nail migration. While introducing the awl it is important to ensure that the opposite cortex is not breached. The nail is introduced and advanced to the fracture site.

Proximal ulnar insertion:

The skin is incised 1.5 to 2 cm transversely over the proximal lateral aspect of the olecranon, 3 cm distal to the apophysis. The lateral cortex of the olecranon is perforated with the awl directed obliquely in a distal direction. The nail is inserted and advanced distally to the fracture site.

DORSAL ENTRY POINT FOR RADIUS

LATERAL ENTRY POINT FOR RADIUS

SURGICAL APPROACH TO ULNA

Reduction and fixation:

Single reduction (Radius)

Because it is more often the difficult step, the radius should be reduced first. Attempt to bring the fracture planes in contact indirectly by percutaneously manipulating the proximal fragment. Rotate the radial nail carefully to line up the tip perfectly with the intramedullary canal of the proximal fragment and then advance the tip into the proximal fragment. Once passage of the nail into the canal has been verified, the nail is advanced proximally to the level of the radial tuberosity. The tip should be directed towards the ulna.

Open reduction (Radius)

Failure to introduce the nail into the proximal fragment requires open reduction. To do so, make a short incision over at the level of the fracture to remove the obstructing soft tissue. Under direct vision, reduce the fracture with small clamps and then advance the tip of the nail into the proximal fragment.

Single reduction (Ulna)

Following reduction of the radius, the ulna usually reduces spontaneously. The ulnar nail is advanced distally to the distal ulnar metaphysis. It is then secured in the strong cancellous metaphyseal bone with the tip rotated towards the radius to produce maximal spreading of the interosseous membrane.

Simultaneous reduction:

If reduction of the radius and/or ulna is difficult, it may be helpful initially to only advance the radial nail as far as the fracture site. Then, proceed with the insertion of the ulnar nail. Now, the reduction can often be accomplished more easily because both nails can be manipulated simultaneously.

Final position of both nails:

The nails are cut and their ends are placed deep in the subcutaneous tissue. Before cutting, the nail is withdrawn by 1 to 2 cms, bent such that the distal end lies flush with the distal part of the bone and re-impacted into the bone. The distal end of the nails should preferably be facing each other. It is also advisable to suture the subcutaneous tissue over the nail end to prevent attrition of overlying tendons. The incisions are then closed with single sutures. The end of the radius nail must be placed sufficiently outside the tendon compartment to prevent constant friction and tendon rupture.

Alternative techniques (Radius):

Many surgeons prefer to insert the radial nail by a lateral approach on the distal radius. The incision here needs to be little longer in order to identify and protect the superficial radial nerve. The awl must carefully be placed directly in the lateral cortex.

Alternative technique (Ulna):

Insertion of the ulnar nail in its distal metaphysis is favored by many surgeons. An incision is placed over the distal medial ulnar metaphysis. The medullary canal is opened with the awl and advance in a retrograde manner. Manipulation of both bones from the same end may be helpful in reducing fracture patterns.

Post operative care and rehabilitation:

Post operative radiographs are taken to confirm satisfactory final alignment. Post operative immobilization is debatable. Although biomechanical testing proves the rotational stability of the intramedullary nailing in the forearm fractures, most authors recommend additional bracing or immobilization with cast. Complications of immobilization line joint stiffness and atrophy are uncommon in children. Radiographs are taken 4 weeks later to demonstrate sufficient callus formation. If significant restriction of pronation and supination continues for more than 3 months after the nail removal, physiotherapy should be initiated with close supervision until full functional recovery has been achieved.

Nail removal:

Though some authors have advocated nail exit as early as 3 months when sound bony union is confirmed on radiographs, it is advisable to delay nail removal up to 1 year. Earlier removal of nail has been associated with higher incidence of re fracture. ESIN promotes early bone union by stimulating both periosteal and endosteal callus formation and it does not disturb the fracture hematoma. The elasticity of flexible nails allows optimum micro-motion which stimulated new bone formation.

Possible complications:

ESIN is a simple method, but failures occur when basic principles are ignored. Though the corrective potential of a child's skeleton contributes to fracture healing despite sub-optimal fixation, it is not an excuse for poor performance

Most failures with ESIN occur due to wrong indication, incorrect nail size, wrong technique and failure by omission. Common post operative complications include:

a) Soft tissue irritation due to sharp nail ends (3%)
b) wound infection
c) Secondary rupture of tendons (3.7%)
d) Re-fracture with nail in situ (2.5%)
e) Axial deviation > 10 degrees (1.8%)
f) Delayed healing (1.2%)
g) Migration of nail (0.6%)
h) Technical failure (0.6%).
i) Functional restriction (limitation of movement > 10 degrees) is reported in 1.8% cases, following radial neck fracture.
j) Distal radio-ulnar joint subluxation has also been cited as a rare complication of this procedure.

Common errors:

- Too narrow nail (<60% of forearm bone diameter)

- Inadequate 3 point contact with the diaphysis
- Inadequate pre bending
- Using different sizes of nails
- Improper nail insertion
- Soft tissue irritation

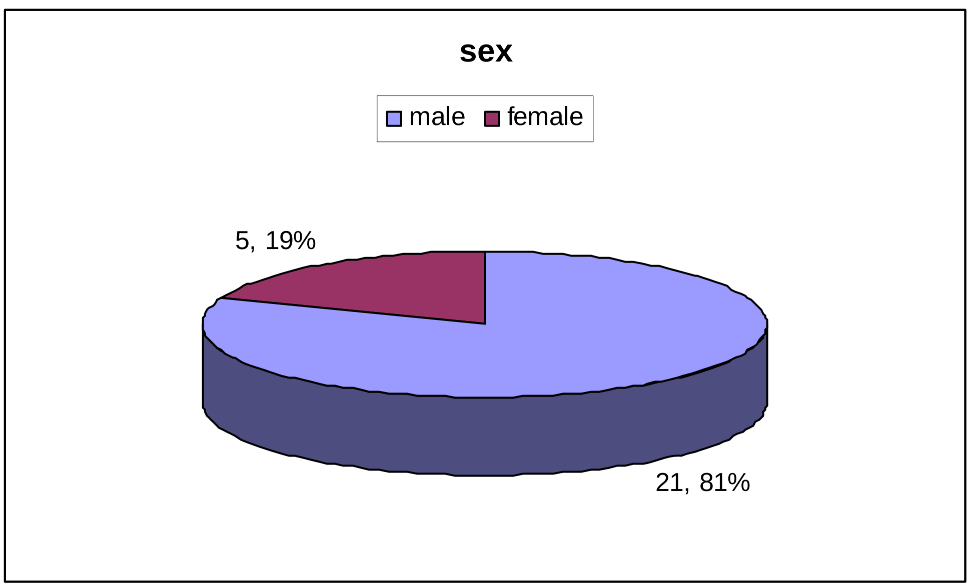
RESULTS

64 children presented with acute forearm fractures from March, 2009 to Feb, 2010 to the specialized pediatric orthopedic department at Christian Medical College, Vellore. Out of which, 8 children underwent internal stabilization of both bones of the forearm with flexible nails. Remaining 56 underwent closed reduction and cast immobilization. Some required stabilization with percutaneous Kirschner wires. Indications for operative management were – unstable both bones forearm fractures in older children and adolescents, unacceptable malalignment after attempted closed reduction under sedation and general anesthesia and open fractures. We do not have the accurate number of all the children with forearm diaphyseal fractures who presented to the emergency department at our institution over the past 7 years. 26 children underwent operative management for both bone forearm diaphyseal fractures during the same period. That's an average rate of 3.7 cases per year. We can confidently extrapolate these figures to imply that a less than 10 % of diaphyseal forearm fracture in pediatric population required operative management, while the rest were managed with traditional conservative method.

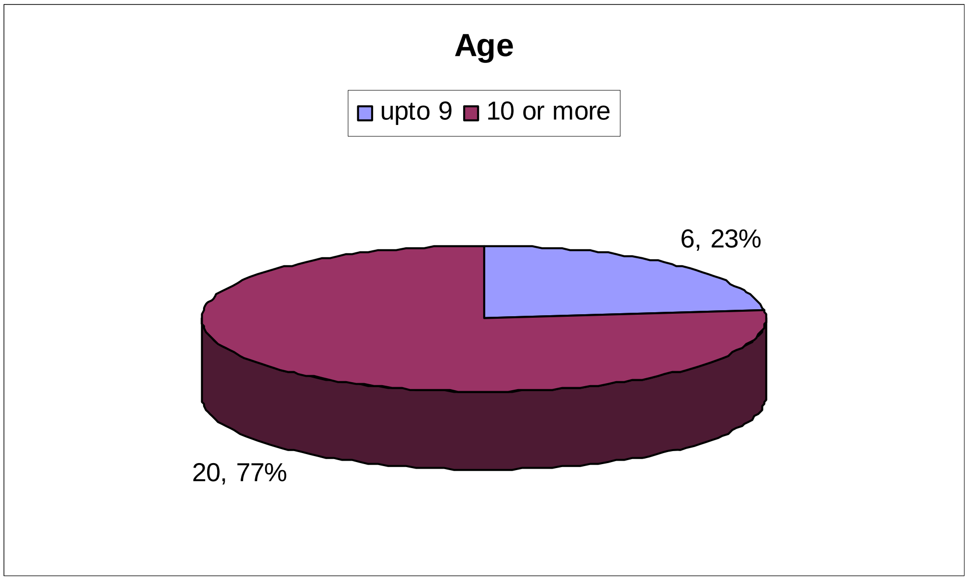
In 11 out of 26 patients, flexible nailing was done as primary treatment; remaining underwent closed reduction under sedation. Unacceptable malalignment after closed reduction and inherent instability in these 15 patients was the indication for internal fixation. Among the 11 patients who underwent primary internal fixation 10 patients presented with compound fracture of the forearm and one patient was 15 year old adolescent (Table 1).

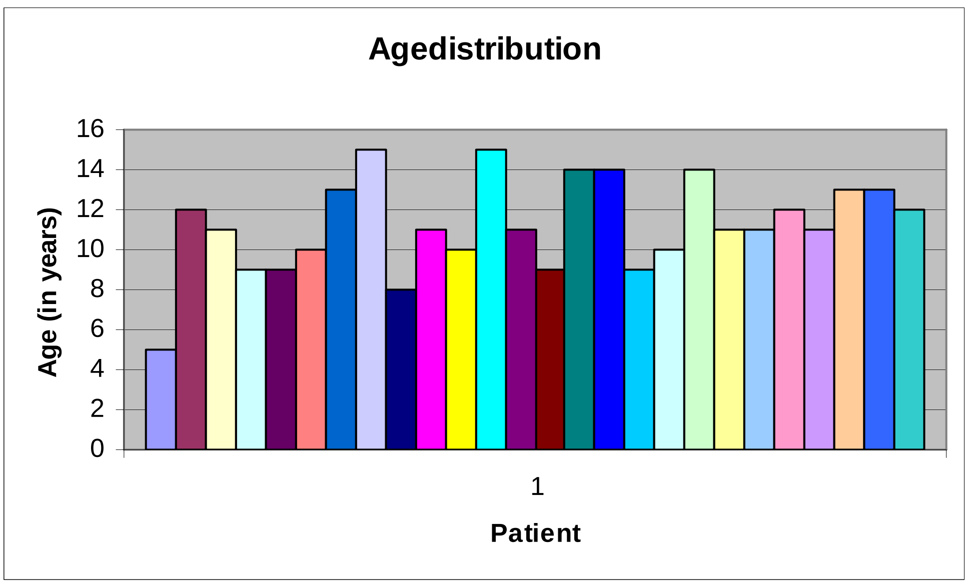
24 out of the 26 children underwent ESIN within 24 hours after sustaining the injury. 2 patients had delayed procedure. In one case, we waited for 1 week for the wound to heal after the primary debridement, thus converting a compound injury to a closed injury. This child was 13 years old and had an unstable fracture pattern involving the proximal third of the radius and middle third of the ulna shaft; he underwent closed reduction and internal fixation with flexible nail. There was no delay in bony union in this patient. The second patient presented with delayed secondary displacement 2 weeks after the primary closed reduction. He required open reduction and flexible nailing of the radius, while ulna was closed reduced and internally fixed. Bony union occurred within 6 weeks. He had good functional outcome.

There were 21 boys and 5 girls in our group.

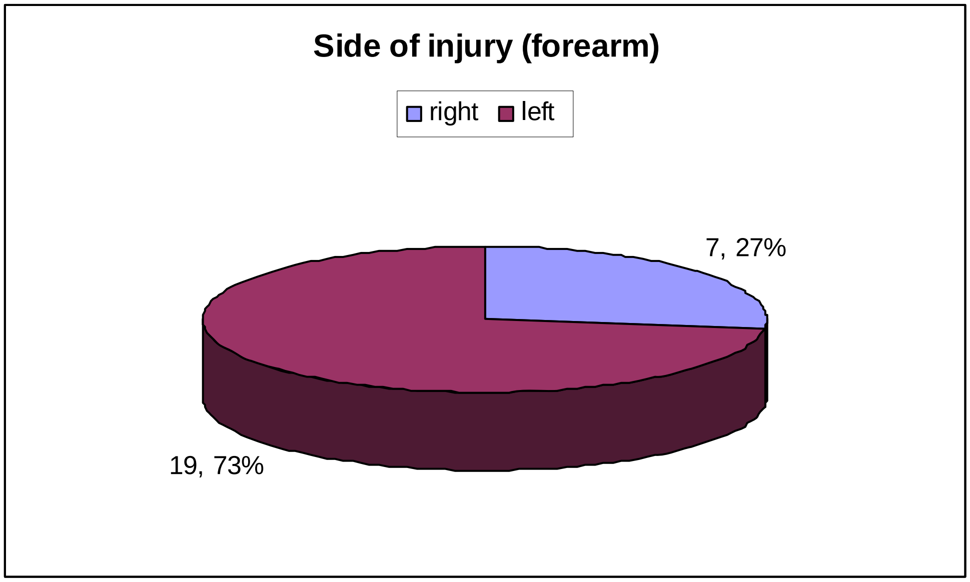


The average age was 11.23 years, ranging from 5 years to 15 years. The youngest patient was 5 years old, who underwent ESIN for type I open displaced diaphyseal fracture of both bones of forearm. 20 patients were older than 10 years. Of the 6 patients who were less than 10 years old, 4 were 9 years old.





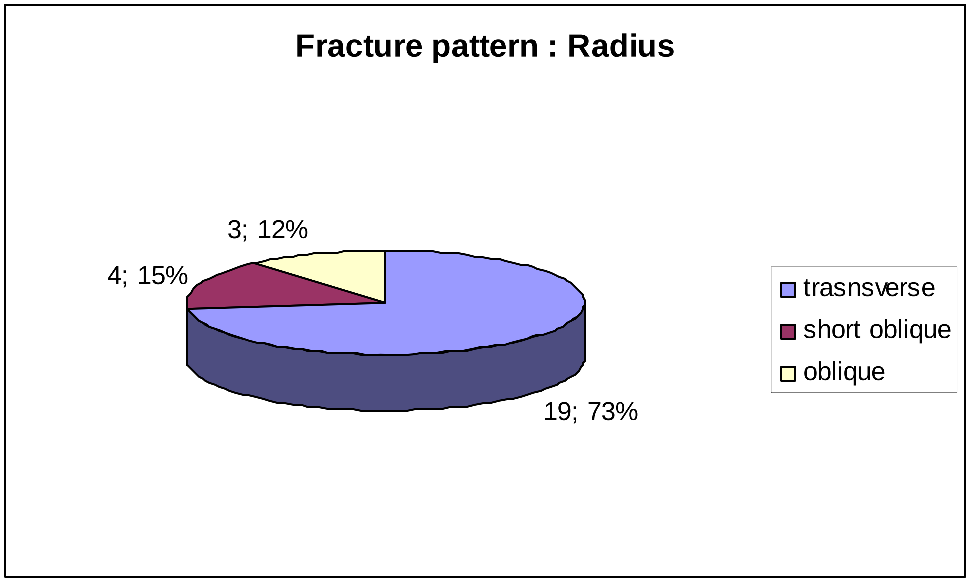
19 children had sustained injury to the non dominant left forearm and 7 patients sustained injury to the right forearm.

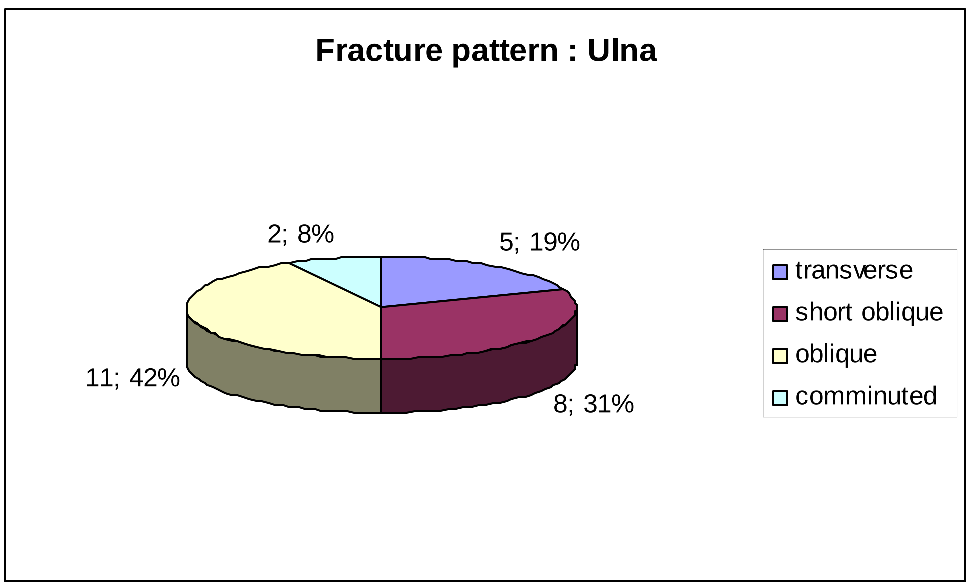


In 18 children the diaphyseal fractures of both radius and ulna were at the same level and the interosseous space was compromised. The radial fracture was located more proximal in 8 cases.15 out of the 18 children sustained fracture of middle third both bones of forearm. 2 patients had both bones fracture of the proximal third and one 13 year old child had a displaced fracture of the distal third diaphysis of both forearm bones.

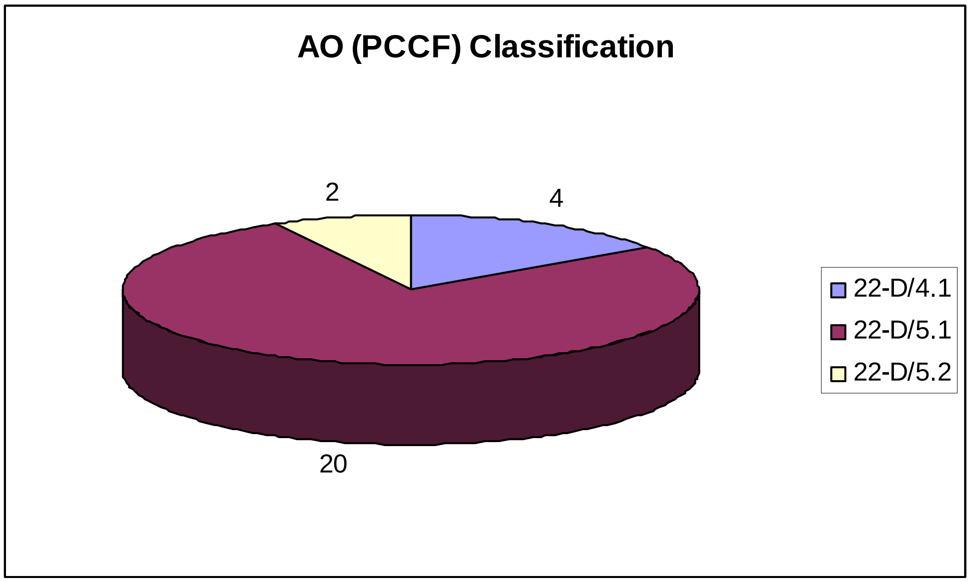
	Radius	**Ulna**	**Total**
Proximal	**9**	**2**	**11**
Middle	**16**	**23**	**39**
Distal	**1**	**1**	**2**
Total	**26**	**26**	**52**

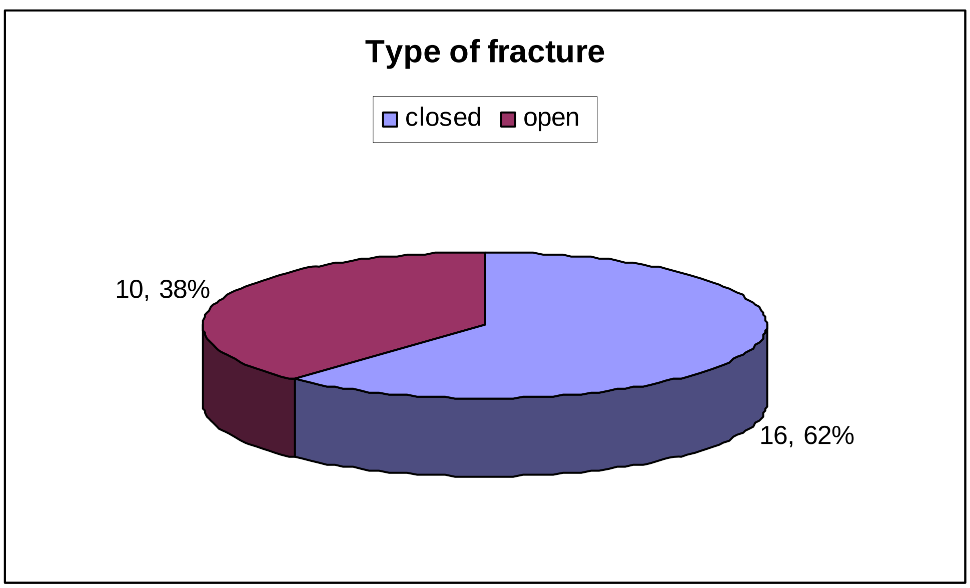
The fracture pattern of the radial diaphysis was transverse in 19 children, short oblique in 4 children and oblique in 3 children. The fracture pattern of the ulna diaphysis was transverse in 5 children, short oblique in 8 children, oblique in 11and comminuted in 2 cases.



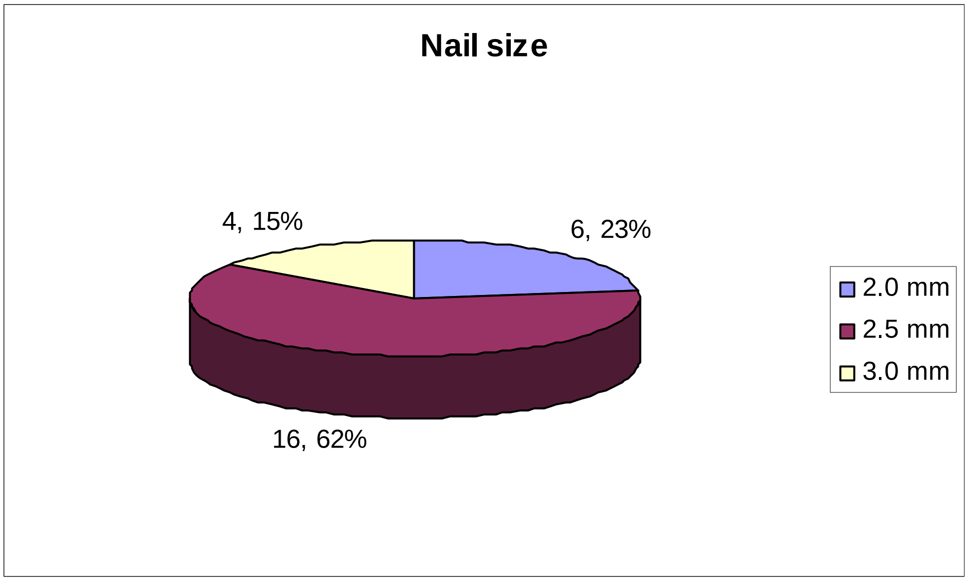


All fractures were classified according to the AO Pediatric Comprehensive Classification of Long Bones Fractures (PCCF) system (89). 20 children were classified as AO 22-D/5.1. Four children were classified as 22-D/4.1 and two children with comminuted fractures were classified as 22-D/5.2.



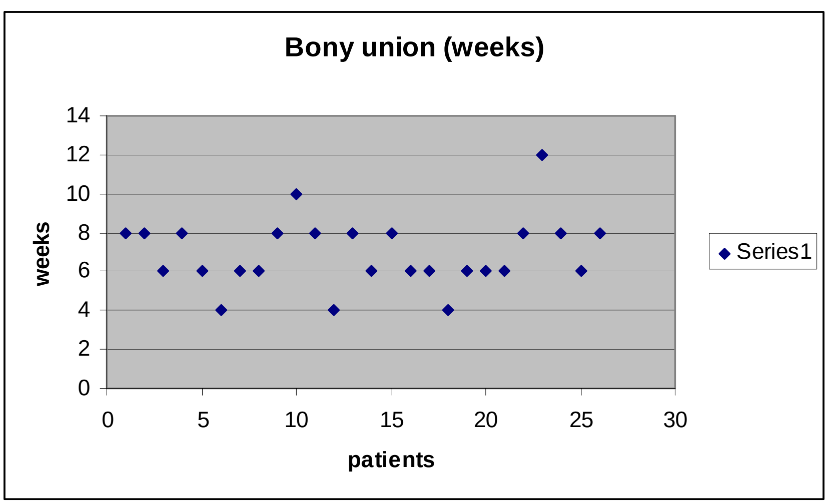


The procedures were carried out by pediatric orthopedic consultants, pediatric orthopedic fellows and post graduates in pediatric orthopedics department. The diameter of the nails used were 2.0 mm in 6 cases, 2.5 mm in 17 cases and 3.0 m in 3 cases.



Two patients underwent open reduction for the radius fracture.

The average time for fracture healing and bony union was 6.92 weeks. One patient with Type I open fracture of both bones of forearm bony united at 12 weeks. Another child with proximal third both bones forearm fracture had fracture union at 10 weeks.



The radial and ulnar angulations in orthogonal planes were within the prescribed normal limits in all but 2 patients. The average angulation was less than 5 degrees. In one case the radial angulation was 12 degrees and it was probably due to use of inadequate nail size (too small) resulting in loss of three point contact. In another child there was 15 degrees of radial angulation where the cause was probably the proximal level of both bones fracture, which limited the maneuverability and control over the proximal fragments and insufficient three point contact.

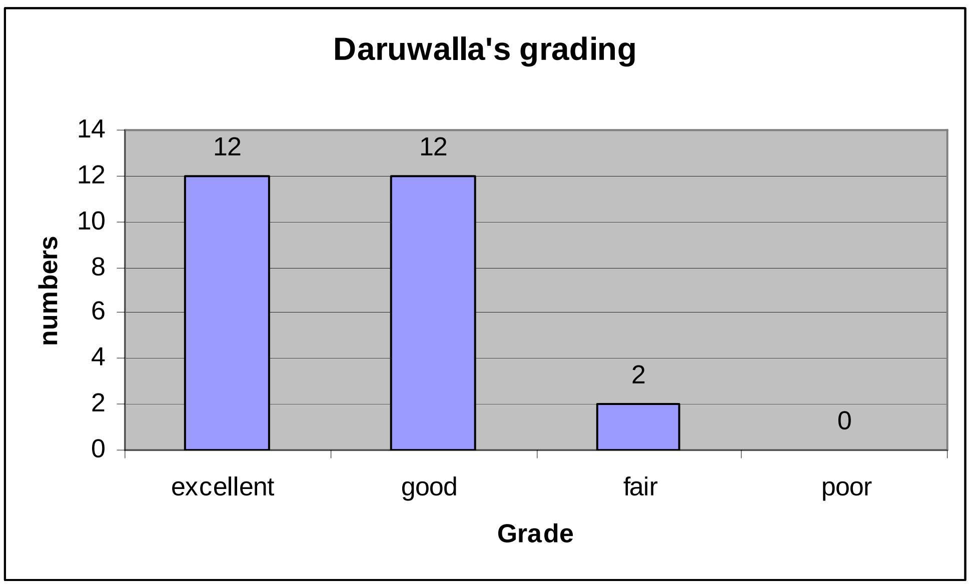
The average hospital stay for closed forearm fractures was 3.66 days and for open fractures was 6.5 days.

Implants were removed in 12 patients at an average internal fixation – implant exit interval of 63.16 weeks. Two patients required early implant exit at 20 weeks after the internal fixation, due to hardware complications. In both cases nails were removed after bony union.

All patients were immobilized for 4 to 6 weeks after the primary surgery as well as after implant exit, after which supervised physiotherapy was initiated. Only two patients had mild restriction of terminal wrist movement. One patient developed a 20 degrees fixed flexion deformity of the elbow secondary to a prominent Ulna nail which caused a mechanical block to full extension.

Three patients complained of persistent paraesthesia over the superficial radial nerve distribution. Three patients developed hypertrophied scars over the nail entry points. One patient had pre operative ulnar nerve injury, which recovered completely. One patient had associated cervical spine injury with no deficits and was treated conservatively with hard collar.

24 patients had excellent or good results according to the Daruwalla's clinical grading. Two patients had more than 20 degrees rotation deficits of the operated limb but did not complaint of any significant functional disability. 2 patients had more than 10 degrees of angular deformity. One had 12 degrees and another had 15 degrees of malalignment. Their functional outcome was not affected by this deformity. Group 1 consisted of 9 patients with more than 2 years of follow up. 6 of them reported excellent and 3 had good results. There were no poor results in group 1. Group 2 consisted of 17 patients who had less than 2 years follow up. 6 patients reported excellent results, 9 had good results and 2 patients had fair results in this group.



21 children completed the PODCI upper extremity functional assessment questionnaire. The normative PODCI upper extremity functional assessment score ranges from -140 to 53. Higher score implies better outcome. 7 belonged to group 1 and 14 belonged to group 2. The mean PODCI scores were comparable between both groups. The mean PODCI upper extremity functional assessment score for group 1 was 51.285. While 6 scored a maximum 53 points, one patient scored 41. The mean PODCI upper extremity functional

assessment score for group 2 was 50.285. 11 patients scored 53, 2 patients scored 41 and 1 patient scored 39. All 4 children who scored less than 53 on the PODCI upper extremity functional assessment questionnaire had good or fair results as per Daruwalla's clinical grading. But not all who scored 53 on PODCI questionnaire had excellent grading on clinical examination. This of course reflects the functional adaptability of pediatric age group.

We used the modified Schemitsch and Richard's method to calculate the location of radial bow in the children who underwent flexible nailing. The mean distance of the site of the radial bow was located at 64.73% (SD +/- 6.5%) of the radial length. The mean value of maximum radial bow was 5.71% (SD +/- 0.79%). It is comparable to Firl's criteria which specify that the mean distance of the radial bow should be around 60% and the maximum radial bow should be less than 10% of the radial length. In view of lack of standardized values of x/y ratio and maximum radial height for Indian children, it is difficult to comment whether a distal migration of maximum radial bow occurred or not, as expected following internal fixation of radius (49, 67). But there was no limb length discrepancy between the operated and non operated limbs in our group.

The average cost of two intramedullary nail varied between Rupees 8000.00 to Rs 10000.00. Cost analysis was done for all patients taking inflation factor into account. The analysis revealed that the expenses incurred during the entire hospitalization were approximately Rupees 25000.00. This cost can be justified considering that surgery was offered to patients with relevant indications for operative management, who otherwise might have ended up with resultant deformity requiring corrective osteotomy or significant life style modification and altered self perception. There was no observed case of refracture.

CLINICAL ASSESSMENT:

FOREARM SUPINATION

FOREARM PRONATION

FOREARM SUPINATION

FOREARM PRONATION

FORFARM RANGE OF MOVEMENT

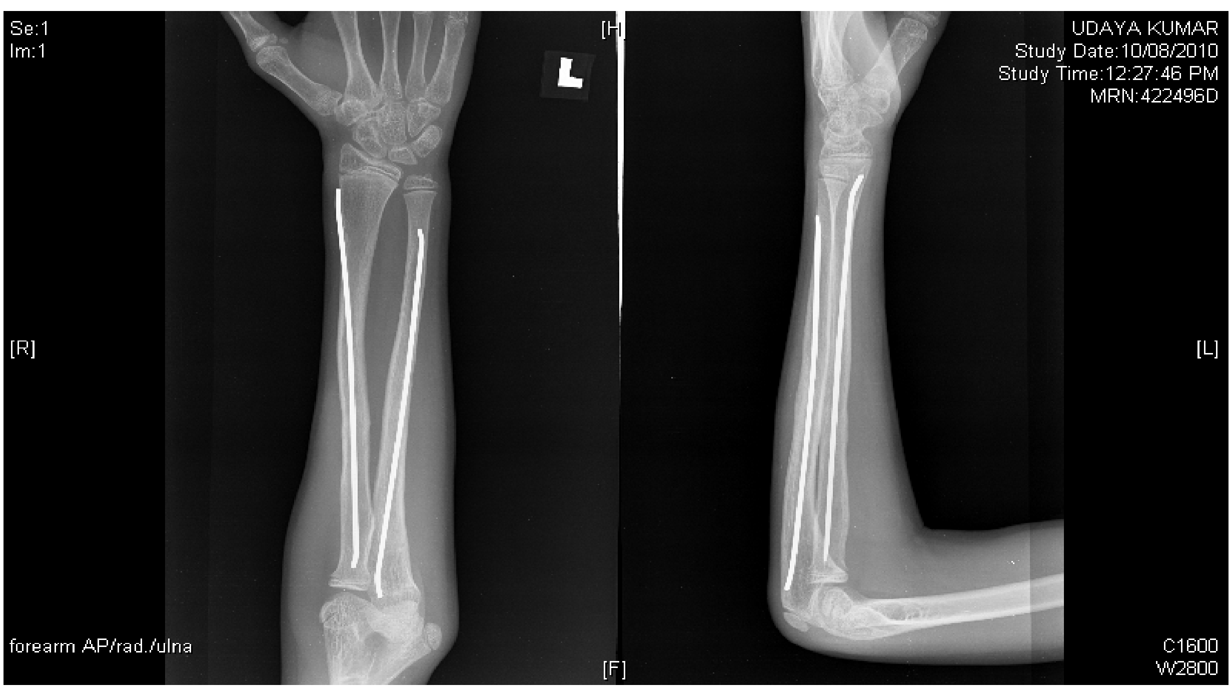
ELBOW RANGE OF MOVEMENT

LIMITATION OF RIGHT FOREARM PRONATION

LIMITATION OF TERMINAL SUPINATION OF LEFT FOREARM

Illustrative example 1 (14 year old boy with failed closed reduction)

Bony union at 6 weeks:



Illustrative example 2 (14 year old boy with failed closed reduction)

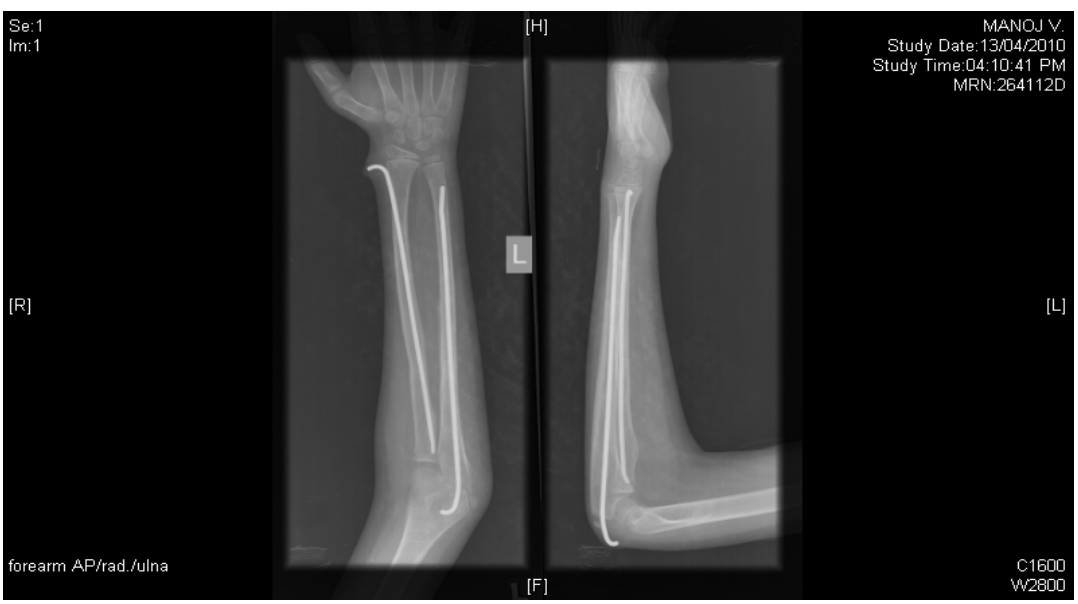
Radiograph at first follow up OP visit:

Illustrative example 3 (5 year old boy with type I open, comminuted fracture forearm)

Bony union at 8 weeks:

Illustrative example 4 (Unacceptable reduction for proximal third both bones forearm fracture in 10 years old boy):

Soft tissue irritation caused due to inaccurate nail placement. Implant exit was done at 20 weeks:



Illustrative example 5 (prominent Ulna nail in a 15 year old boy with forearm both bones ESIN). Implants were removed at 20 weeks:

Illustrative example 6:

Accurate position of radial and ulna nail should be verified intra operatively under Image Intensifier:

Illustrative example 7 (Unstable both bone forearm fracture in a 9 year old girl):

Bony union at 6 weeks:

Inadvertent injury to the distal radial physis at the time of implant exit (100 weeks after internal fixation):

Resulting in distal partial radial physeal arrest:

DISCUSSION

The management of forearm fracture in children is undergoing a change with the realization that closed reduction with some deformity in children is acceptable and will remodel. The literature has shown that the results of closed reduction irrespective of instability and higher degree of deformity and malalignment have caused unacceptable cosmetic and functional results (15, 17). With the available information the present criteria for acceptable angulation, displacement and rotation are much stricter (3). The acceptable limits of angulation and malrotation in completely displaced both bones forearm fractures are 15 and 45 degrees respectively in children under 9 years and 10 and 30 degrees respectively in children over 9 years (3). The complications of correcting a malunited, functionally compromised pediatric forearm far outweighs those of primary internal fixation of unstable forearm fracture (32, 34, 37).

The commonest indications in literature for internal fixation for pediatric both bones forearm fracture are fracture instability, mal-reduction or loss of reduction and children older than 10 years. In our group 60% had mal-reduction or loss of reduction. 20(77%) children were 10 years or older. Instability, mal-reduction and loss of reduction account for 50% to 90% internal fixation described in the literature (19, 36, 44, 45). An unusual indication in our children was open fractures because of fall from height leading to high velocity injury. 40% of our children sustained an open injury to the forearm. Of the 10 children who sustained open injury, 8 had type I open injury and 2 had type II open injury. 8 out of these children were over 10 years of age.

The pattern of fracture in the unstable group is usually complete, transverse, oblique or short oblique. 24 of our 26 children fitted this category and two being comminuted and even more unstable. Literature has shown that approximately 10 % of all pediatric forearm both bones fractures are unstable and warrant internal fixation (37, 12, 79). As a corollary, 80% of internal fixation in the pediatric forearm both bones fractures is secondary to instability. 15 out of our 26 patients in our group underwent attempted closed reduction under anesthesia. All had unacceptable malalignment and the average angulation was more than 30 degrees. According to Price's criteria this degree of angular malalignment was unacceptable (3). Mean age of our group was 11.23 years (range 5 to 15 years). The young children with thick periosteum and relatively elastic bones tend to sustain Green stick fractures and stable fractures, whereas the older children are prone to sustain complete, unstable, angulated and malrotated fractures which require to be treated with reduction and internal fixation, as is seen the current study.

In our study all children who underwent ESIN for both bones forearm fractures united at the first follow up except for an open fracture and another child who took 12 and 10 weeks respectively to unite. The fast healing is in contrast to plate osteosynthesis (49). Contradictory reports have been published comparing closed reduction and mini open reduction. Closed reduction and open reduction with mini open incision have produced comparable results (86). Flynn et al reported delayed bony union associated with open reduction and intramedullary nailing (68).

There are many implant related issues in elastic stable intramedullary nailing such as biomechanical properties of various intramedullary devices and both bone versus single bone fixation. Owing to the elastic nature of the Titanium nails, there can be a relative movement of up to 2 degrees at the fracture site(36) during pronation – supination. Immature skeleton with thick periosteum not only augments the stability but also promotes healing by external callus formation. The flexibility of the nails allows microscopic oscillating movements at the fracture site and applies varying amount of compression at the fractures site. Several authors advocate use of prebent Kirschner wires instead of Ti nails. Kirschner wires made of stainless steel have a lower modulus of elasticity; hence they are more rigid than Ti nails (59, 63). It has also been proved that Kirschner wires are more resistant to axial compression forces and torsion forces than Ti nails (63). But these properties do not necessarily mean that Kirschner wires are more suitable than Ti nails for intramedullary nailing. Because they are more rigid, Kirschner wires produce stress shielding, have higher risk of cut out and increase the risk of refracture both before as well as after implant exit (62, 63). Rigid Kirschner wires are more prone to breakage as they have lower bending threshold than titanium nails. If titanium nails are not available then use of Kirschner wires is an option. Kirschner wire must be removed between 3 to 5 months operatively (18).

Radius and ulna function as a single unit and requires one nail in each forearm bone to stabilize fractured both bones. A new school of thought promotes single bone intramedullary nailing in both bones fracture and closed reduction of the other (68). The idea being, a single internally stabilized bone helps to achieve and maintain alignment of the closed reduced second bone. Of course the limb has to be immobilized in a cast for a period to 6 weeks. The outcome results are believed to be comparable to that of both bones flexible nailing (68). However, doubts have arisen following reports of secondary displacement requiring open reduction and internal fixation (44). We choose to nail both bones as recommended by most authors (57, 38). We do not have any experience in single bone nailing for both bones forearm fracture.

Choosing the appropriate nail size is a significant issue. Elastic stable intramedullary nailing is based on the principles of converting traction and shearing forces acting at the fractured fragments into compression force. It produces a dynamic three point cortical apposition (37, 48, 57). A prebent elastic nail introduced in a long bone produces compression at its convex side and distraction at its concave side. A second same diameter prebent elastic nail introduced in a reversed C shape produces exactly the opposite effect. Thus two nails provide maximum cortical apposition, maintain length and give rotational stability (44, 45, 48). In order to do this, the elastic nails must together occupy at least 80 % of the medullary canal diameter (57). The most common nail size was 2.5 mm. There was one case in where we found the nail size was suboptimal and that resulted in 12 degrees of malalignment. This probably was due to non availability of appropriate size of nail at the time of surgery. This further emphasizes the fact that a wide array of flexible nails ought to be there in the armamentarium of an orthopedic surgeon managing such unstable fractures operatively. Concerns about non availability and cost effectiveness of flexible Titanium nails have been raised. Indigenous Titanium flexible intramedullary nails are available now within the range of Rs 1500 and are cheaper than some of the plating constructs available.

There also continues the debate regarding need for post op immobilization of the operated upper limb in an above elbow slab. Theddy Slongo dismisses it by comparing internal fixation with internal decoration if it required external stabilization (57). While immobilization is certainly indicated when Kirschner wires are used as the intramedullary stabilizing device or when single bone is internally fixed in both bones fractures (18, 44, 68), consensus for post operative immobilization in flexible nailing in both bones forearm fractures has evaded pediatric orthopedic community. In our department, we prefer to immobilize the operated forearm in an above elbow posterior slab with elbow in 90 degree flexion and forearm in neutral rotation for a period of 4 weeks. Stability provided by the flexible nails is relative and not rigid (48). There is a risk of loss of rotational and angular alignment in the post operative period (44). Repeat fall can lead to bending of the intramedullary nails (73). Besides, risk of joint stiffness secondary to immobilization in children is negligible (45). Hence, giving children the benefit of doubt, it is probably preferable to immobilize the operated forearm with flexible nails in situ for 4 to 6 weeks. It also helps in decreasing the post operative edema, pain and promotes a sense of caution on behalf of the patient (29).

Needless to say that a conservatively treated forearm needs observation and strict supervision to avoid and promptly intervene in devastating complication such as compartment syndrome leading to Volkmann's ischemic contraction. Similarly patients who undergo closed reduction and internal fixation with intramedullary flexible nails also require admission for careful monitoring. The average hospital stay for patients with closed fracture was less than that among the open fracture group. It did not exceed more than 4 days and often the decision to stay for longer duration was based on the family convenience and preference.

These are not urgent cases and should be done in next available elective operation list after adequate planning. 24 out of the 26 children underwent internal fixation within 24 hours after sustaining trauma. The remaining two presented late.

In the past the choice of implant for operative management of pediatric forearm fractures has been similar to those of the adults, which is plate osteosynthesis. Normal anatomical alignment can be obtained with open reduction and internal fixation with $1/3^{rd}$ tubular plates or 3.5 mm / 2.7 mm dynamic compression plates. They provide rigid internal fixation and better rotational alignment than flexible nails (20).

In children this has several disadvantages. The amount of periosteal and soft tissue dissection associated with plate osteosynthesis is extensive. The complications associated with plate removal, especially that of the radius are many and associated with significant risk of posterior interosseous nerve injury (58).

Refracture risk is also higher after plate removal which are load sparing devices as compared to intramedullary fixation (82). Intramedullary nailing is a more favored operative procedure because it does not disturb the fracture biology. The fracture hematoma is left undisturbed when closed reduction and internal fixation is successful. Even in those cases where open reduction is essential and in open fractures, flexible nailing involves minimal soft tissue dissection. Elastic stable intramedullary nailing provides longitudinal and angular stability and at the same time does not disturb fracture site or the fracture hematoma (36, 45, 57). Hence it is considered a patient friendly technique, because it promotes biological fracture healing.

ESIN is a more cosmetic procedure than open reduction and internal fixation with plates, because it can be accomplished through smaller incisions. Healing is arguably better in the intramedullary nailing patients associated with fewer incidences of complications such as delayed union and non union. Implant removal is also safer in intramedullary nails. ESIN involves less deep tissue dissection and less operative time than plate osteosynthesis (31, 36, 49). Blasier and Salama have questioned the rotational stability of pediatric forearms treated with intramedullary fixation. Ono et al believe that the strong periosteum in children prevents rotation and hence correction of rotational malalignment. Intramedullary fixation of both bones reduces fracture rotation to one eighth of that in unfixed fractures (57).

There was no non union in our case series. Delayed union and non union have been described less frequently with conservative management of pediatric diaphyseal forearm fractures (80). Several authors having compared plate osteosynthesis and intramedullary fixation have found higher risk of delayed union and non union among the former group (82). Similarly, open forearm diaphyseal fractures are associated with longer healing time and more prone to delayed or non union (83).

No refracture occurred in our group. Literature has shown that stiffer stainless steel Kirschner wires make forearm bones prone to refracture after implant removal. Risk of refracture has traditionally been higher among the plate fixation group.

Plate removal is associated with significant complications. Approach through an already scarred tissue increases the risk of nerve injury and compromises the vascularity of the surrounding soft tissue as well as that of the bone (58). After plate removal the forearm bones are susceptible to refracture. In contrast, hardware removal of intramedullary nails is not only easier but also less time consuming and technically simpler.

There is a debate regarding need for implant removal in intramedullary Titanium flexible nails, in view of the bio-mechanical compatibility of Titanium with bones. The risk of long term implant related malignancy is extremely miniscule (84). Rare case reports have identified Titanium implants used in certain dental procedures to be associated with sarcomas, but the incidence is very small (85). Besides, the causal relationship between implants and carcinogenesis is yet to be established. It has been pointed out that implant related sarcomas usually present on an average 9 years after implant application (84). In view of the long life of our patients, one expects the implant to be in situ for 50 to 80 years. We cannot scientifically justify removal of intramedullary elastic Titanium nails, but prefer removing them after adequate surgery – implant exit interval of at least 1 year as a safer option.

Clinical outcome following elastic stable intramedullary fixation with Titanium nails in this study showed 12 excellent and 12 good results. Remaining two had fair results, one with a type II open fracture which required a secondary STSG and another had a type I open fracture. He had 30 degree restriction of pronation. The second patient had a type I compound fracture and was irregular with follow up.

Jubel et al reported excellent / good results in 44 out of 51 children treated with flexible nails for both bones diaphyseal forearm fractures (47). They used Price's criteria for clinical evaluation, which slightly differs from the Daruwalla's grading used in our study. Richter et al found excellent / good results in 29 of the 30 children who underwent elastic intramedullary nailing (45). Luhmann et al reported excellent / good results in all 25 patients (36). Lascombes and Metaizeau found 92% of their 80 patients had excellent results following intramedullary forearm both bones nailing (22).

The novelty of this study was objective outcome analysis using the PODCI questionnaire and score. It has not been done commonly for pediatric forearm trauma (64, 88). High PODCI outcome score corroborate the excellent / good results in this group. The PODCI outcome score was comparative between those who had less than 2 years follow up and those with more than 2 years follow up. Maximum functional score was achieved in 1 year. Follow up for more than 1 year therefore seems unnecessary and should be limited for those children who have any growth related issues.

We achieved < 10 degree post operative angulation in all but two patients. There was 12 degrees angulation in one patient in whom the nail size was too thin to maintain reduction. But it did not affect his forearm range of movement. The second incident was in a case of proximal third both bone forearm fracture, where it was difficult to achieve adequate control over the proximal fragments. A 15 degree angulation restricted his terminal 10 degree of supination and 20 degrees of pronation.

After comparing the pros and cons of various internal fixation devices, one can certainly argue in favor of using flexible Titanium intramedullary nails in unstable pediatric forearm fractures (31, 63). Literature suggests that dynamic compression plates are indicated when rigid fixation is desired as in children older than 16 years who should be treated according to the adult protocols.

Only 12 of the 26 patients underwent implant removal. There was no refracture in either group. Early hardware removal (within 3 months) was done in two children. Both had symptomatic, hardware related complications.

Time to bony union and functional outcome of our series is comparable to similar analysis groups (37, 40, 41, 44, 47, 48). The mean PODCI upper limb functional assessment score was high in our series. Functional outcome assessment was carried out according to Daruwalla’s clinical scoring system and PODCI upper limb assessment score. Excellent and good functional outcome was documented in 24 patients (12 patients in each category). 2 patients had fair outcome. There was no poor outcome.

Universal acceptance of flexible nailing as the state of the art technique for unstable pediatric forearm fractures has raised concerns over its overuse and abuse. A wide spectrum of complications can be viewed through the kaleidoscope of successive publications in international literature. They are broadly classified into major and minor complications. Major complications are defined as those which require re-operation and those who don't need re-operation and do not significantly affect outcome are loosely grouped together and called minor complications. Rare incidents of delayed union and pseudoarthrosis have been reported (51, 69, 70, 71, 72). In most cases excessive soft tissue handling, open reduction and technical error are the culprits. We did not have any delayed union or non union in our case series.

Cullen et al reported 4 cases of wound infection, 2 cases of loss of reduction and 5 cases of hardware migration causing skin irritation in a series of 20 cases (51). One of the 4 cases of wound infection that occurred in a type II open fracture progressed to chronic osteomyelitis. Though there was no delayed union or non union, he reported one case of synostosis in a proximal third both bones forearm fracture. He used Kirschner wires as the intramedullary fixation device in all his patients. Schoemaker et al reported excellent outcome in 31 out of 32 patients following intramedullary K wire stabilization (50). K wires were removed within 6 months. He noted loss of reduction after removal of K wires in 3 children and refracture in 2 patients. We did not have any refracture or loss of reduction in our group.

Carmichael compared 15 patients who underwent internal stabilization of unstable both bones forearm fracture with intramedullary flexible nails with 16 patients who underwent open reduction and plate osteosynthesis (78). He reported excellent to good results in both groups, with 2 minor complications. Shah et al also compared the intramedullary group with plate osteosynthesis group and found as many as 5 major complications in the latter group including nerve injury as against none in the former (49).

Kapoor et al reported their findings in 50 successive patients who underwent flexible intramedullary nailing of forearm bones in Southampton, UK (43). 45 had both bones fractures. 26 patients underwent open reduction, which is much higher than the general trend. He reported one case of delayed union of ulna. Smith et al compared the incidence of complication rates between flexible intramedullary nailing and open reduction and internal fixation with small fragment dynamic compression plates (69). The complications rates of flexible intramedullary nail group and plate osteosynthesis group were comparable. He reported 2 cases of malunion and one non union of the ulna shaft fracture. Fernandez et al published a case series of 6 pseudoarthrosis of ulna among 537 patients in a 16 year follow up series. 5 of these cases underwent open reduction and 4 were refractures following previously healed forearm fractures. 4 children underwent nail exit and plate osteosynthesis while spontaneous bony healing occurred in 2 patients (70).

Malunions, refractures, compartment syndromes, neurological and vascular injuries, tendon ruptures due to chronic attrition and rare non unions basically sums up the possible complications in pediatric forearm fractures (36, 76, 77).

We did not have any major complications in our series. Minor complications included superficial radial nerve paraesthesia, hypertrophied scars and superficial wound infections. Our series had 3 patients who developed paraesthesia over the superficial nerve distribution. 3 patients had hypertrophied scars and one patient had superficial wound infection over the ulna entry point. One patient underwent elective second look surgery and wound washout following internal fixation for open forearm fracture. Wound healing was uneventful.

There was one case of distal radial physeal injury which occurred during implant removal rather than due to intramedullary nailing. The distal radial physis was inadvertently damaged while removing the radial nail in one child. She developed a medial and dorsal physeal arrest and had restriction of terminal 10 degrees of wrist dorsiflexion. This complication has not been described earlier and was entirely related to surgical misadventure. This incident occurred in a child in whom hardware exit was attempted through the previous scar but the distal end radial nail had migrated proximally. This case highlights the need for adequate preoperative work up, planning and supervision by a specialist prior to the relatively simple procedure of removing intramedullary nails in children.

All the radial nails were introduced through the radial styloid. Hence, there was no incidence of tendon ruptures. But the lateral surgical approach to the distal radius seems to increase the risk of injury and irritation of the superficial radial nerve. Protrusion of hardware endangered the superficial skin and warranted early removal in two children. One of these cases was due to a modified technique of ulna nailing which was subsequently abandoned. An overwhelming majority (more than 90%) of our patients reported excellent and good clinical outcome and a similar picture was reflected in the PODCI upper arm functional outcome score.

Considering the good results obtained in the grossly unstable and open diaphyseal fractures of pediatric forearm bones, we propose flexible intramedullary nailing as a novel method in our scenario, for internal stabilization of unstable pediatric forearm diaphyseal fractures.

I close this discussion with the following questions:

1. Are we justified in accepting suboptimal reduction and compromised functional outcome in children because they adapt and do not complain?

2. Cast immobilization in children causes discomfort similar to the adult population, if not more. In unstable and grossly malaligned forearm fractures, any accrued advantage due to conservative management is offset by functional compromise. In this scenario, is there a justification for persisting with traditional methods for this voiceless special group of patients despite scientific evidence to the contrary?

3. Conservative management is the gold standard for pediatric forearm fracture management, but yet it is not credited with cent percent functional outcome in older children, adolescents and open fractures. In our group, majority of children underwent internal fixation after failed reduction. Is there a need to state that certain forearm injuries such as unstable, complete, displaced and malreduced diaphyseal both bones fractures of forearm in older children should be considered indications for primary surgical intervention?

CONCLUSIONS

This series is too small to draw high end conclusions for pediatric forearm fracture management. Having said that, the general trends that we witnessed during the course of this study points to the following conclusions:

1. Elastic stable intramedullary nailing is a safe and reliable method for internal fixation of unstable forearm fractures.
2. Deviation from the basic principles of ESIN which includes choosing the suitable size and material of flexible nail, suitable nail entry point and surgical approach, will lead to avoidable complications
3. Lateral entry point for radial nail puts the superficial radial nerve at risk.
4. The functional results at 1 year are maintained and uncomplicated cases may be discharged from regular follow up at this period.
5. Immobilization during the immediate post operative period for 4 to 6 weeks is advisable.
6. Hardware exit is not a must and decision for the same has to be tailored for every patient.

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DATA COLLECTION CHART – TABLE 1

Patient	Age at fracture (years)	Sex	Open / Closed fracture	Bony union (weeks)	Duration of follow up (weeks)	Limitation of forearm rotation	Daruwalla's Score	PODCI score (max 53)
1	5	M	Open Type I	8	330	nil	Excellent	53
2	12	M	Open Type I	8	210	20 degrees of supination	Good	53
3	11	M	Closed	6	268	nil	Excellent	
4	9	M	Closed	8	312	nil	Excellent	53
5	9	F	Closed	6	280	nil	Excellent	53
6	10	M	Closed	4	209	20 degrees of supination	Good	53
7	13	M	Closed	6	207	10 degrees of supination and pronation	Good	41
8	15	M	Closed	6	168	nil	Excellent	
9	8	F	Closed	8	86	nil	Excellent	53
10	11	F	Closed	10	96	10 degrees of supination and pronation	Good	53
11	10	M	Closed	8	56	nil	Excellent	
12	15	M	Open Type I	4	28	10 degrees of supination	Good	39
13	11	F	Closed	8	78	nil	Excellent	53
14	9	M	Open Type II	6	80	10 degrees restriction of pronation	Good	53
15	14	M	Closed	8	72	10 degrees restriction of supination and pronation	Good	41
16	14	M	Open Type I	6	72	20 degrees of pronation	Good	53
17	9	F	Closed	6	56	10 degrees of pronation	Good	53
18	10	M	Open Type I	4	184	nil	Excellent	53
19	14	M	Closed	6	70	nil	Excellent	
20	11	M	Closed	6	38	nil	Excellent	53
21	11	M	Closed	6	56	20 degrees restriction of supination	Good	53
22	12	M	Open Type I	8	50	20 degrees	Good	53

						restriction of pronation		
23	11	M	Open Type II	12	40	30 degrees restriction of pronation	Fair	41
24	13	M	Open Type I	8	30	30 degrees restriction of supination	Fair	
25	13	M	Closed	6	32	nil	Excellent	53
26	12	M	Open Type I	8	28	10 degrees restriction of supination and pronation	Good	53

COMPLICATIONS (DATA COLLECTION – TABLE 2)

Patient	Age at fracture (years)	Sex	Open / Closed fracture	Surgery - Implant exit internval (weeks)	Complications
1	5	M	Open Type I	70	nil
2	12	M	Open Type I	No exit	nil
3	11	M	Closed	60	nil
4	9	M	Closed	158	nil
5	9	F	Closed	100	Distal radial physeal arrest at the time of implant exit
6	10	M	Closed	156	nil
7	13	M	Closed	No exit	nil
8	15	M	Closed	20	Bursa over Ulna entry point
9	8	F	Closed		
10	11	F	Closed	54	Hypertrophied scar
11	10	M	Closed	20	Bursa over Radial entry point
12	15	M	Open Type I	No exit	nil
13	11	F	Closed	58	nil
14	9	M	Open Type II	No exit	nil
15	14	M	Closed	No exit	Hypertrophied scar and superficial radial nerve paraesthesia
16	14	M	Open Type I	No exit	nil
17	9	F	Closed	53	nil
18	10	M	Open Type I	160	Hypertrophied scar
19	14	M	Closed	54	Superficial wound infection over ulna entry point
20	11	M	Closed		nil
21	11	M	Closed	No exit	nil
22	12	M	Open Type I	No exit	nil
23	11	M	Open Type II	No exit	nil
24	13	M	Open Type I	No exit	nil
25	13	M	Closed	No exit	Superficial radial nerve paraesthesia
26	12	M	Open Type I	No exit	Superficial radial nerve paraesthesia

Fracture Pattern Classification (AO –PCCF) Table 3:

Patient	Open / Closed fracture	Radius	Ulna	AO Classification
1	Open Type I	TRANSVERSE	COMMINUTED	22-D/5.2
2	Open Type I	TRANSVERSE	OBLIQUE	22-D/5.1
3	Closed	OBLIQUE	OBLIQUE	22-D/5.1
4	Closed	TRANSVERSE	OBLIQUE	22-D/5.1
5	Closed	TRANSVERSE	SHORT OBLIQUE	22-D/5.1
6	Closed	SHORT OBLIQUE	SHORT OBLIQUE	22-D/5.1
7	Closed	TRANSVERSE	OBLIQUE	22-D/5.1
8	Closed	SHORT OBLIQUE	SHORT OBLIQUE	22-D/5.1
9	Closed	TRANSVERSE	TRANSVERSE	22-D/4.1
10	Closed	TRANSVERSE	TRANSVERSE	22-D/4.1
11	Closed	TRANSVERSE	SHORT OBLIQUE	22-D/5.1
12	Open Type I	TRANSVERSE	SHORT OBLIQUE	22-D/5.1
13	Closed	TRANSVERSE	OBLIQUE	22-D/5.1
14	Open Type II	SHORT OBLIQUE	TRANSVERSE	22-D/5.1
15	Closed	TRANSVERSE	TRANSVERSE	22-D/4.1
16	Open Type I	TRANSVERSE	OBLIQUE	22-D/5.1
17	Closed	TRANSVERSE	OBLIQUE	22-D/5.1
18	Open Type I	OBLIQUE	OBLIQUE	22-D/5.1
19	Closed	TRANSVERSE	SHORT OBLIQUE	22-D/5.1
20	Closed	TRANSVERSE	TRANSVERSE	22-D/4.1
21	Closed	TRANSVERSE	OBLIQUE	22-D/5.1
22	Open Type I	TRANSVERSE	OBLIQUE	22-D/5.1
23	Open Type II	TRANSVERSE	OBLIQUE	22-D/5.1
24	Open Type I	SHORT OBLIQUE	SHORT OBLIQUE	22-D/5.1
25	Closed	TRANSVERSE	SHORT OBLIQUE	22-D/5.1
26	Open Type I	OBLIQUE	comminuted	22-D/5.2

PORFORMA – Forearm ESIN study

NAME
AGE
SEX
HOSPITAL NUMBER
FATHER'S NAME
ADDRESS

MODE OF INJURY
SIDE OF INJURY - RIGHT / LEFT
OPEN / CLOSED
DATE OF INJURY - / /
DATE OF SURGERY - / /
INDICATION

- INSTABILITY
- OPEN FRACTURE
- UNACCEPTABLE REDUCTION

COMPARTMENT SYNDROME - YES / NO
DELAYED WOUND HEALING - YES / NO
HARDWARE COMLICATION – YES / NO
SECONDARY PROCEDURE - YES / NO
DURATION OF IMMOBILIZATION - (IN WKs)
WRIST ROM

- DORSIFLEXION
- PALMARFLEXION

FOREARM ROM

- SUPINATION
- PRONATION

ELBOW ROM -
DURATION TO BONY UNION - (IN WKs)
DURATION TO IMPLANT EXIT - (IN WKs)
REFRACTURE – YES / NO
RADIAL ANGULATION

- AP PLANE
- LATERAL PLANE

ULNAR ANGULATION

- AP PLANE
- LATERAL PLANE

ROTATIONAL MALALIGMENT

- RADIUS
- ULNA

DARUWALLA'S SCORE

- EXCELLENT
- GOOD
- FAIR
- POOR

PODCI / POSNA SCORE

<u>PODCI Outcomes Questionnaire</u>

Developed by:

American Academy of Orthopaedic Surgeons®

Pediatric Orthopaedic Society of North America

American Academy of Pediatrics

Shriner's Hospitals

To be completed by adolescents

Based on the Version 2.0 Pediatrics–Adolescent Outcomes Intrument

Also commonly referred to as the PODCI ("Pediatric Outcomes Data Collection Instrument")

Revised, renumbered, reformatted August 2005

Upper Extremity and Physical Function Core Scale:

Name:

Age:

Sex:

Hospital Number:

Father's name:

Self report / Parent report

1. During last week, easy/hard to: Lift heavy book?
   1=Easy
   2=A little hard
   3=Very hard
   4=Cant do at all

2. During last week, easy/hard to: Pour a half gallon of milk?ks?
   1=Easy
   2=A little hard
   3=Very hard
   4=Cant do at all

3. During last week, easy/hard to: Open a jar that has been opened before?
   1=Easy
   2=A little hard
   3=Very hard
   4=Cant do at all

4. During last week, easy/hard to: Use a fork and spoon?
   1=Easy
   2=A little hard
   3=Very hard
   4=Cant do at all

5. During last week, easy/hard to: Comb your hair?
   1=Easy
   2=A little hard
   3=Very hard
   4=Cant do at all

6. During last week, easy/hard to: Button buttons?
   1=Easy
   2=A little hard
   3=Very hard
   4=Cant do at all

7. During last week, easy/hard to: Put on your coat?
   1=Easy
   2=A little hard
   3=Very hard
   4=Cant do at all

8. During last week, easy/hard to: Write with a pencil?
   1=Easy
   2=A little hard
   3=Very hard
   4=Cant do at all

Raw Score:
Mean of Items:
Standardized Score:
Normative Score: